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BIOLOGY OF THE LOTUS BORER (PYRAUSTA PENITALIS Grote).

By GEORGE G. AINSLIE, *Entomological Assistant*, and W. B. CARTWRIGHT, *Scientific Assistant, Cereal and Forage Insect Investigations, Bureau of Entomology.*

CONTENTS.

INTRODUCTORY.

In American literature two distinct species have been confused under the name *Pyrausta penitalis* Grote. One of them, the smartweed borer, has recently been described as new under the name *P. ainsliei* by Carl Heinrich (*16*[1]), of the Bureau of Entomology. The other, the lotus borer, described originally by Grote (*1*) and later redescribed by Smith (*3*) as *Botis nelumbialis*, has been casually studied by several observers, but up to the present time no complete account of its biology has been available. The two species are closely related and very similar, in many morphological and biological characters, to the recently introduced European corn borer, *P. nubilalis* Hübner. It seemed possible that a close study of the life history and habits of the two native species might bring to light some facts which would help in determining the potentialities of the new pest. In accordance with this plan the first paper dealing with *P. ainsliei* from the biological side has already been published (*18*). The present paper deals with the similar aspects of *P. penitalis*. Both the results

[1] Reference is made by number (italic) to "Literature cited," p. 13.

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of the writers' observations and previously published data are included herein. The morphology and diagnostic characters of this and the other species mentioned, which have already been admirably worked out by Heinrich (*16*) and also by Flint and Malloch (*17*) and Mosher (*13*, *15*), are largely omitted from this discussion.

SYSTEMATIC HISTORY.

Pyrausta penitalis was first described by Grote (*1*) under the generic name Botis from material taken on *Nelumbo lutea* at Lawrence. Kans. In 1890 it was redescribed by Smith (*3*) as *Botis nelumbialis* from "Egyptian" (more properly "Indian") lotus, *N. nucifera*, at Bordentown, N. J. Thinking that he was dealing with this species, Coquillett (*2*) published some notes on a form which has since been shown (*12*, *14*) to be distinct, probably *P. futilalis*. Riley and Howard (*4*, *p. 349*, Townsend (*5*, *p. 467*), Coquillett (*7*, *pp. 15*, *17*, *19*, *27*), and Viereck (*11*, *p. 453*) record parasites which will be more fully noted later. Hart (*6*, *p. 180*), gives some scattered biological information and descriptions of the various stages as observed on *N. lutea* along the Illinois River. Coquillett (*7*) first used the name in its present form, and Dyar (*9*, *p. 391*) lists the species as occurring in the south Atlantic States, with *B. nelumbialis* Smith as a synonym. Chittenden (*12*) summarized all the facts available up to the time of his paper and from them formulated a tentative life cycle which, because of the fact that he was considering two species, one of them at the time undescribed, will have to be considerably modified. Welch (*14*) has made the latest contribution to our knowledge of the species, and his observations, made at Sandusky Bay, Lake Erie, although good, are incomplete as to life history, because they covered only a small part of the growing season. His conclusions, however, come nearer the facts than any hitherto published.

STUDIES AT KNOXVILLE, TENN.

FIELD COLLECTIONS.

The authors' work on the species dates from July 19, 1919, when, after considerable search, a plantation of the yellow lotus or water chinquapin (*Nelumbo lutea*) (Pl. I) was located at Kimberlin Heights, about 15 miles from our laboratory at Knoxville, Tenn. This plantation consisted of a dense border of the plants surrounding a mud-bottomed pond of about 3 acres on the campus of a small denominational school. It was said that the plants had started several years before from seeds thrown into the pond by one of the students. As nearly as the authors have been able to ascertain, this is now the only occurrence of the plant in eastern Tennessee, although it is known

that before the coming of the white man the Indians cultivated it for its edible seeds and rootstocks in many places along the Cumberland and Tennessee Rivers.

The first examination showed that the plants were heavily infested by the very insect the writers desired to study. Throughout the rest of the season of 1919 frequent careful studies were made of the conditions at Kimberlin Heights, and quantities of material were brought to the laboratory for closer study and for rearing purposes.

At the time of the first visit, July 19, the main blooming season was closing. There were still a few flowers and scattering buds. None of the seed pods had ripened, but the oldest ones were fully grown. A count showed that there were 472 pods in all stages in the plantation. Of these, 80 (17 per cent) showed work of the larvæ and were collected and examined individually. They contained 39 empty pupal shells, 23 pupæ, and 2 larvæ in the prepupal stage. Moths began to emerge at once, or, more properly, continued to emerge from the pupæ until July 28, when the last one appeared.

On July 19, larvæ, evidently the progeny of the earliest moths, were found feeding on the leaves. These larvæ were mostly small, only a few half grown, and none mature. When taken to the laboratory for rearing they began to pupate July 28, and the first moths of this generation emerged August 4. From this time on there was a continual overlapping of generations, larvæ both from the later moths of the first generation and from those of the second being inseparably mixed. From these larvæ and from others collected on July 28, moths continued to emerge until August 27. On August 5 no very small larvæ could be found. The youngest observed probably were in the third instar, but several egg masses were found, so it seemed probable that the last moths of the first generation had not yet disappeared. On this same date it was also found that the larvæ of this generation instead of seeking pupation quarters in the seed heads were burrowing in the upper ends of the petioles of the older leaves, preparing there a pupation chamber, and that a few had already pupated. One empty pupa shell was found in this location, which seemingly indicated that the second generation of moths had just begun to emerge. More pupæ and prepupal larvæ subsequently were found in the petioles, and larvæ, in gradually lessening numbers, still feeding on the leaves and in the petioles, were found until September 18. Three were found on this date, but thereafter the most thorough search of the lotus and of all likely hiding places in the vicinity of the pond failed to reveal a trace of their whereabouts.

A further and more careful study in this locality was planned for 1920, but for some obscure reason the lotus was very much less vigorous. Comparatively few leaves and buds appeared and only a few small larvæ were found in colonies on June 29.

REARING RECORDS.

So much for field observations. On each examination of the pond material was collected and brought to the laboratory for rearing. The results obtained throw additional light on the seasonal habits of the moths. As stated above, pupæ taken in the seed heads July 19 continued to develop moths until July 28. Larvæ taken at the same time on the leaves varied greatly in size, some of them being very small. The first of these pupated July 28, the last August 15. Moths emerged from August 4 to August 22. Another collection of larvæ made from the leaves July 28 pupated August 3 to August 18, and moths emerged August 12 to August 27. A mass of eggs found August 6 hatched August 9, and the larvæ were reared. They pupated August 28 to September 2, and the moths emerged September 9 to September 17. Another series of larvæ taken both from petioles and leaf blades on August 5 pupated from August 6 to August 22, and moths emerged August 13 to August 29. Larvæ from a lot of 67 collected August 15 pupated from August 17 to September 12, and moths emerged August 28 to September 22.

LIFE CYCLE.

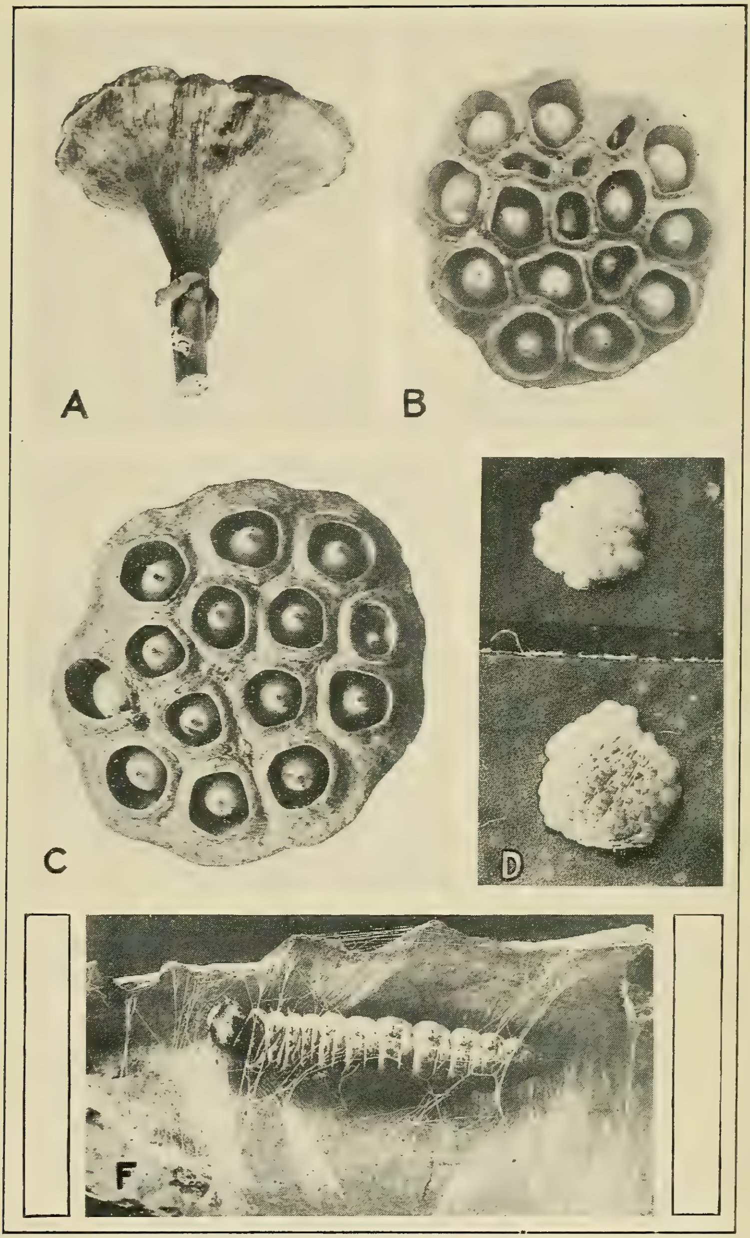
Assuming for the present, as seems probable, that the species passes the winter in the larval stage, it is evident that the life history must be substantially as follows:

The overwintering larvæ pupate and the moths emerge and oviposit about mid-June. The resulting larvæ feed on the leaves, and when fairly grown, about July 1, seek the flowers and enter the young pods, feeding upon them to some extent and pupating within them. The moths of this first generation emerge from July 7 to July 28. Eggs are at once produced by these moths and constitute the first stage of the second generation. The eggs soon hatch, and the oldest of the larvæ produced are approximately half grown by July 19; but moths of the first generation continue to oviposit until about August 5, so that second-generation larvæ are hatching continuously from July 10 to August 8. A collection of these larvæ made July 28 pupated August 3 to 18 and moths emerged August 12 to 27. These larvæ of the second generation feed on the leaves and pupate in the upper ends of the leaf petioles.

The moths of the second generation give rise to the third-generation eggs and larvæ, which survive the winter and constitute the spring generation. It seems possible that some of the smaller larvæ of the second generation seek hibernation quarters instead of completing their growth the same fall. In this case there would be only two generations annually, but it seems probable that there are three generations as a rule. Their behavior from the time the larvæ seek

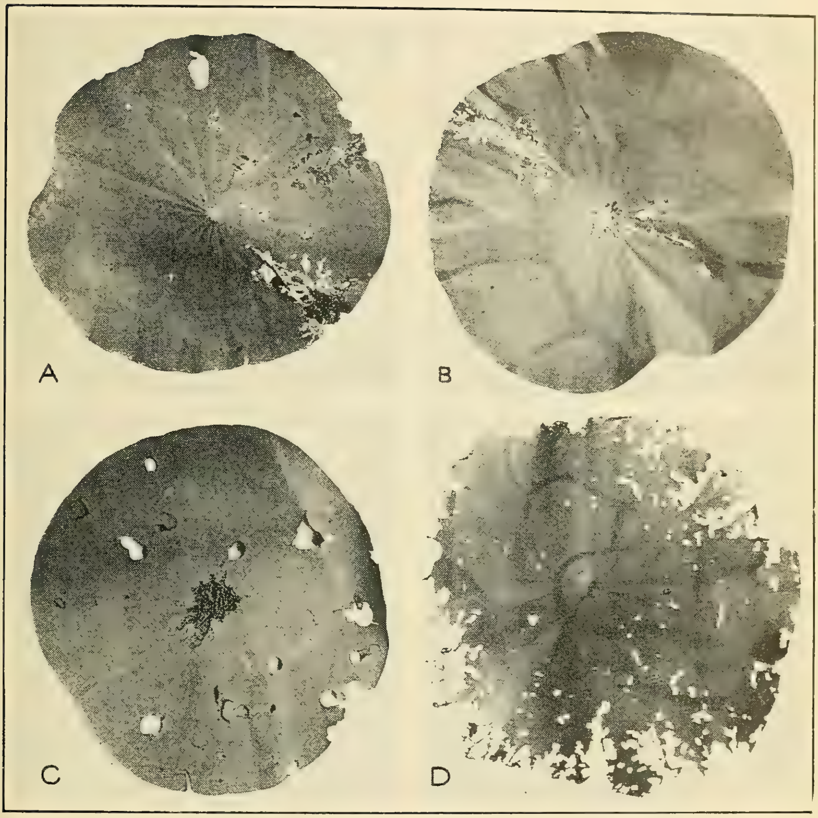
PYRAUSTA PENITALIS.

A, Partial view of pond at Kimberlin Heights, Tenn., showing *Nelumbo lutea* flowers, ripe pods, and margin of old dying leaves floating on water. *B*, Method of pod development in lotus: *a*, Bud; *b*, growing pods in horizontal position; *c*, erect, mature pods; *d*, pod deformed by work of borer.



PYRAUSTA PENITALIS.

A, Under side of infested pod, showing entrance hole of borer. *B*, Same pod as in *A*. Face view showing deformed sockets and seeds caused by work of larva beneath. *C*, Face of another pod, showing less common method of entrance. *D*, Egg masses on leaf surface. *F*, Larva beneath web on leaf.



PYRAUSTA PENITALIS.

A, Injured leaf. *B*, Leaf bearing both central and peripheral feeding areas. *C*, An old floating leaf, showing mound of frass covering the opening to the pupal chamber in the petiole beneath. *D*, An old, much eaten leaf after the remaining membrane has dried and dropped out.

PYRAUSTA PENITALIS.

A, Portion of plantation at Kimberlin Heights, Tenn., showing close association of lotus and cat-tail rush. *B*, Upper end of leaf petiole, opened to show pupal cavity and cocoon. *C*, Same as in *B*. Leaf cut in half and petiole split to show position of pupal cavity.

winter quarters in the fall until the young larvæ of the first generation appear on the leaves in June is unknown, and the outline here given for that period is hypothetical.

FEEDING HABITS ON THE LEAVES

After hatching, the larvæ feed gregariously for a time, gnawing off the epidermis of the leaf in irregular patches, first protecting themselves with a shielding network of brownish silk stretched across some slight concavity of the leaf or producing such a concavity by its tension. They soon scatter, each forming a similar retreat of its own (Pl. II, F), either in the center of the leaf above the petiole attachment or around the margin where the edge is easily drawn up a little to form the necessary free space beneath the web (Pl. III, A, B). Less often a larva locates on the blade between the center and the margin. Protected and partially screened by the webs, the larvæ strip the epidermis from the leaf, those at the center in a more or less radiate pattern and those at the margin following the periphery. They extend their retreat as they exhaust the food supply and occasionally prolong the feeding area irregularly inward toward the disk of the leaf. At no stage is the entire substance of the leaf eaten. The areas from which the epidermis is stripped soon turn brown, dry, and fall out, leaving the leaf lacelike along the margin (Pl. III, D) and generally tattered in appearance.

Although at Kimberlin Heights no larvæ were observed in the act, it is evident that they moved about from leaf to leaf and from one portion of a leaf to another. Small feeding webs were often found uninhabited, and tiny larvæ were found in retreats evidently occupied previously by much larger ones. Where several larvæ occurred on one leaf the retreats often overlapped around the margin, giving the effect of a large retreat occupied by several larvæ. No evidence was found of the larvæ swimming from one leaf to another as was observed by Welch in Lake Erie. The leaves were in almost every case contiguous to each other, especially when swayed by the breeze, and no need for such a means of locomotion was apparent. Then, too, the old floating leaves, loose from their petioles, drifted back and forth across the pond before the wind and, working in among the standing leaves, formed pontoon bridges between the petioles. (Pl. I, A.)

One exceptional instance was observed in which a leaf standing somewhat by itself but not especially isolated was found with a series of six holes in the petiole between the blade and water, each of which opened into a short cavity containing a fully mature larva evidently preparing to pupate. Not another larva was found in such a location, and this case can only be explained on the ground

that the larvæ marooned on this leaf, unable to seek their usual pupation quarters, were forced to enter the petiole.

From laboratory experiments it was found that when placed in water the larvæ, especially those nearly mature, were sustained on the surface film and were able to make considerable progress by lateral contortions. When once fully submerged, however, they were unable to regain the surface. Larvæ of *Pyrausta ainsliei* under the same conditions behaved similarly but did not advance as rapidly when swimming.

FEEDING HABITS ON THE PODS.

The larvæ of the first generation apparently utilize the green, growing pod for food as well as for pupation. After the floral parts fall away, the pod normally droops (Pl. I, B, *b*) until its flat, seed-bearing face is vertical, becoming erect again when nearly mature (Pl. I, B, *c*). Until maturity the seeds remain tightly embedded in their sockets, and only as the pods ripen, turn brown, and dry do they become loose, ultimately to be shaken out and sink in the water and mud around the plants.

In entering the young pod the larva usually selects a point just below the rim and on the underside of the pod as it hangs horizontally (Pl. II, A); less often it cuts in between the seeds on the flat face of the pod (Pl. II, C). As the larva feeds within, soft brown frass is pushed out of the entrance hole in considerable quantity, eventually drying and falling away or being washed off by rain. The interior of the fruit or pod is filled with parenchymatous tissue through which run the vascular bundles nourishing the developing seeds. After entering, the larva eats out more or less of a cavity in this soft tissue and often cuts into or through two or three or more of the seeds. Whenever a seed is injured even slightly or the vascular bundle beneath it is cut, it turns brown and soon shrivels to a mere remnant. These empty or partially empty sockets (Pl. II, B) are very conspicuous and almost invariably indicate the presence or work of the larvæ. Such injured pods are also frequently much distorted (Pl. I, B, *d*) and very unlike the ornamental, perfect specimens. Although in a few cases the cocoon was found near the face of the pod and, in fact, lying partially in and through some of the injured seeds, the larva usually makes its way well toward the base of the pod before cocooning.

In the pods collected at Kimberlin Heights July 19 the normal number of seeds per pod varied from 10 to 25, with an average of 17. The work of the larvæ resulted in the destruction of 5.9 seeds on the average in each infested pod, or 34.7 per cent of the total number in the infested pods and 5.88 per cent of those in the entire plantation. The pods developing from the scattering flowers which

continue to appear after the main blooming season are generally smaller, contain relatively few seeds, and often have empty sockets due to incomplete fertilization.

So far as is known, this lotus has at present no economic value other than its very obvious qualifications as an ornamental plant. The work of the larvæ of this insect on the leaves (Pl. III) is conspicuous and unsightly, and the attacks on the pods result in many misshapen and distorted specimens as well as in the outright destruction of an appreciable proportion of the seeds.

PUPATION OF THE FIRST GENERATION.

Pupæ of the first generation are formed in dense, tough, papery cocoons in the growing pods. The cocoon is not conspicuous even when the pod is opened, as it is stained and studded with brownish excrement like the walls of the burrow. In the great majority of cases it lies well toward the base of the pod with its long axis parallel with the vascular bundles running to the seed sockets. Less often it is found lying partially within or through one or more of the partly consumed seeds. The cocoon and pupa are so much larger than the seeds that it seems impossible for the pest ever to be accidentally distributed in them. Larvæ have been found lying entirely within a single immature seed but never a pupa. In the cocoon the pupa lies with its head toward the entrance, and after emergence occurs the pupal shell remains entirely within the cocoon. The moth escapes from the pod by the same opening through which the larva entered it.

PUPATION OF THE SECOND GENERATION.

In the second generation the pupal habits are quite different, and considerable search was required to locate the cocoon and pupa. Even though a few pods continued to develop from stray flowers, they were found attacked by larvæ in only one or two cases, and the increasing number of larvæ reaching maturity made it certain that they were seeking other quarters. Two possibilities were open—the over-curled margins of the leaves and the petioles. The leaf margins yielded only a very occasional pupa, not enough to solve the problem, and the petioles, standing as they did from 15 to 30 inches above the water and offering apparently ideal conditions for a pupal burrow, remained unscarred. To be sure, an occasional shallow pit was found in the upper end, opening to the upper surface of the leaf blade, but never one large enough to contain a larva.

The lotus at least in this plantation holds the leaves high above the water on their stiff and milky-juiced supporting petioles until, either from maturity or because of serious injury to the leaf surface, they have about reached their limit of usefulness. The petioles then

weaken and allow the leaf disks to drop to the surface of the water (Pl. I, A), where they soon yellow, decay, and sink. When these mature floating leaves were examined it was found that in the center of the disk, directly above the petiole attachment, a large number of the leaves had a round opening leading to a cavity in the upper end of the petiole (Pl. IV, B, C). This cavity was shallow, seldom extending more than 2 centimeters into the petiole, and usually just long enough to accommodate the larva and its cocoon. The entrance was often surrounded and covered by a mound of soft brown frass pellets (Pl. III, C), and frequently the surface tissue of the leaf in an irregular area about it was scarred and eaten as if the larva after constructing the cavity possessed still an appetite which it satisfied with the nearest food at hand.

In the case of the prepupal larvæ or pupæ the cavity in the petiole is lined with a substantial white silk fabric, densest at the upper end (Pl. IV, B). The entrance is closed with a very accurately cut whitish lenticular disk of plant tissue which fits closely and is sealed in with silk. This disk lies usually a little below the level of the leaf surface and is concealed by the frass until the latter is washed away or otherwise removed. This position of the pupal cavity, in the floating leaves only, brings it below the water level.

Welch (*14, p. 219–221*) has well described the construction of this pupal chamber and the feeding in connection therewith, and the behavior of the insects was found here to correspond closely with his account. It is noteworthy, however, that in Lake Erie, where his observations were made, the lotus leaves are always floating and not held above the water, and their centers are higher than the periphery, while at Kimberlin Heights the leaves are held 15 to 30 inches above the water and are cupped with the margins higher than the centers, so that they often catch rain or dew to the amount of several cubic centimeters and hold it until it evaporates or is spilled by the swaying of the leaves in the wind. The insect evidently prefers to construct its cocoon in an aquatic situation and so seeks the old floating leaves at the approach of maturity. Never were young or partly grown larvæ found in the petioles, only those nearly mature and probably in the last instar. Neither are the young and erect leaves attacked in this way; only the old, floating ones.

HABITS OF THE MOTHS.

The only moths seen in the open were the few found in and near the lotus plantation. Several of them were captured and found to be predominantly males. Their flight was rapid and erratic, and they were wary and not easily approached. They came to rest usually on the lower side of a lotus leaf and often flew among the petioles and beneath the canopy formed by the leaves 2 or 3 feet

above the water. No data are available as to the length of life of the moths in the open. A series of reared moths retained alive in tin boxes supplied with a wad of wet cotton furnished the data on this point contained in Table I.

TABLE I.—*Length of life of reared moths in confinement (in terms of days).*

Sex.	Maximum.	Minimum.	Average.	Number of moths averaged.
Male	14	2	6.77	27
Female	13	3	7.72	43

THE EGG.

The act of oviposition has not been observed, but very probably occurs toward dusk or at night. Nothing was known about the egg until Welch (*14, p. 214*) observed and rather incompletely described it. The authors have found numbers of the masses (Pl. II, D) at various times, and as their observations differ in some points from those of Welch a description in somewhat greater detail is included.

The egg: Thin, flat, elliptical in outline, 0.98 millimeter long, 0.56 millimeter wide, chorion finely reticulated with narrow elevated lines and in addition finely longitudinally wrinkled, dingy yellow or amber color when laid, soon developing a narrow darker border and a paler opaque central area. They are laid in thick circular masses of 40 to 80 eggs, 2.5 to 3 millimeters in diameter and 0.47 millimeter thick, each egg overlapping its predecessor shingle-fashion, about three-fourths covering it and lying at an angle of approximately 45° with the leaf surface, the mass being dingy yellow in general color. The larva leaves the egg through a transverse slit in the exposed end. After hatching the mass is dirty gray in color, somewhat shining, and much flatter than before. It is then very loosely attached to the leaf and easily removed by a slight touch.

The writers failed to note any matrix such as Welch describes. They did, however, note the frequent absence of the empty egg mass on leaves bearing very small larvæ, but attributed the fact to the ease with which the empty egg mass is washed or blown from the leaf. A number of the egg masses were found, both unhatched and empty, and one in which the eggs were parasitized. They seem to be placed at any point on the upper surface of the leaf and when present on an unblemished leaf are easily seen.

It has, of course, been impossible to determine how many eggs are normally laid by a female in the open. The possibilities are indicated, however, by results obtained from reared moths confined in tin boxes and supplied with moisture. Of 43 females so confined only 15 oviposited. The number of eggs produced by an individual varied from 9 to 504, with an average for the 15 of 143 eggs. These moths

were all isolated before emergence and remained virgins throughout their lives, so these figures are doubtless below the normal.

FOOD PLANTS.

Unless some food plant other than lotus is inhabited by this insect, it is difficult to explain its presence at Kimberlin Heights. From present knowledge of its habits it is inconceivable that it came with the seeds, and no other lotus is known to exist within possible range of flight of this moth. To determine whether the species is indigenous or introduced, the writers have made plantings of lotus seed in several isolated ponds many miles distant from this infestation.

Because of the confusion in the literature between this species and *Pyrausta ainsliei*, several food plants have been attributed to it which manifestly are erroneous. The only natural food plants which have so far been reliably ascertained are the yellow lotus, *Nelumbo lutea*, and the Indian lotus, *N. nucifera*, the latter an introduced species.

Smith (*10*, *p. 525*), mentions having found these larvæ in stems of cat-tail flag, *Typha latifolia*. At Kimberlin Heights conditions were ideal for such a transfer, because the lotus and cat-tail grew intermingled in several places (Pl. IV, A). In attempts to find where the larvæ went for the winter, practically every cat-tail plant in the vicinity of the pond was thoroughly dissected and examined. With the single exception of one larva found behind a leaf sheaf no trace of attacks on this plant were found.

In confinement in the laboratory partly grown larvæ, taken on lotus, fed readily and completed their growth on leaves of smartweed (*Polygonum pennsylvanicum*), buckwheat (*Fagopyrum fagopyrum*), and dock (*Rumex crispus*). In other series, larvæ were reared from egg to adult on the same plants but the authors have never seen any indication that these plants are used as food by this insect under natural conditions. Numerous aquatic and subaquatic plants and a large number of the common wild plants and weeds were offered to the larvæ, but all were refused except those mentioned. It is noteworthy that the normal food plants of *P. ainsliei* are Polygonaceae but that that species can not develop on lotus. There is a suggestion here of some common ancestry for the two species, with members of the Polygonaceæ as their food plants, and that *P. penitalis*, having taken to lotus comparatively recently, has not entirely lost its taste for the smartweed family.

ENEMIES.

In the course of its life several perils threaten the safety of this insect. It does not seem to us that Welch's point (*14*, *p. 218*), as to the construction of the silken web being a special adaptation to its

aquatic environment, is well taken, for many leaf and tree-feeding caterpillars, exposed to the same or to greater risks, do not construct protective webs and, on the other hand, many larvæ living in sheltered and well-protected situations do build burrows or webs—within which to work. Be that as it may, there is probably little danger of wind or waves washing these caterpillars off the leaves.

DIPTEROUS PARASITES.

From living enemies, however, they do not escape so easily. According to the literature four species of tachinid flies have been reared from the larvæ. Townsend (*5*) lists *Exorista hirsuta* O. S. (now *E. vulgaris* Fall.) and *Phorocera comstockii* Will. as having been reared by Forbes in Illinois. Coquillett (*7*, *p. 17*, *19*) adds *Hypostena variabilis* Coq. and *Panzeria penitalis* Coq. to this list. Because of the confusion between *Pyrausta penitalis* and *Pyrausta ainsliei* and the impossibility of finding from the literature the exact source of the material from which the parasites were reared, it is possible that not all of these species attack the true *Pyrausta penitalis*. *Panzeria penitalis*, for one, is known to be a parasite of *Pyrausta ainsliei*, and there is no definite record of its ever having been reared from lotus-feeding larvæ. All of these records should be verified in the light of our more exact knowledge of their hosts.

HYMENOPTEROUS PARASITES.

Among the hymenopterous parasites, *Bracon xanthostigma* Cress. is listed by Riley and Howard (*4*, *p. 439*) as a parasite of this borer on lotus at St. Louis, Mo. Viereck (*11*, *p. 223*) lists *Meteorus communis* Cress. with the simple statement that it parasitized *P. penitalis*. Hart (*6*, *p. 180*) mentions one secondary and two primary parasites, but without determinations. We recognize at least one of his parasites, the braconid, making white cocoons singly on the leaf surface. (Pl. III A.) This one, determined as *Apanteles harti* Vier. by A. B. Gahan, was found to be the most common at Kimberlin Heights. Its small white cocoons (1.5 by 4 millimeters) are firmly fastened to the leaf disk either under the webbing or exposed outside. In July they were only occasionally seen, but by early September were much more common and were killing from 10 to 25 per cent of the larvæ. This species evidently attacks the smaller larvæ and completes its life as a parasite when its host is scarcely more than half grown. None of them developed from larvæ larger than this. From 7 to 10 days elapsed between the spinning of the cocoon by the parasite and the emergence of the adult.

Another parasite, very likely the other mentioned by Hart (*6*, *p. 181*), which the writers found only a little less common than the foregoing, is an undescribed, yellowish brown species of Microbracon (de-

termined by Gahan). The parasitic grubs to the number of about a dozen emerge from their host larva shortly before time for the pupation of the latter. They then spin a mass of brown silk cocoons so tightly compacted that it is difficult even to determine their number. This mass is found in the burrow or partially constructed cocoon of the host. In more than one instance adults of this parasite were found well within the larval burrow of the host, evidently hunting opportunities for oviposition, but it is not known just how or at what age the host larvæ are attacked.

In three instances *Chalcis ovata* Say (det. Rohwer) was reared from the pupæ by the authors.

The authors found but one case of egg parasitism. One egg mass was taken which appeared darker than normal. When retained in a vial, part of the eggs hatched normally, but the rest, which had meanwhile turned jet black, gave forth adults of *Trichogramma minutum* Riley (det. Gahan), one from each egg.

SCAVENGERS.

Very often small dipterous maggots were found in the empty burrows or feeding on decaying larvæ or pupæ. A number were reared, and two species of flies were obtained, *Aphiochaeta chaetoneura* Malloch (det. Greene), and *Elachiptera nigriceps* Loew (det. Aldrich). These were undoubtedly scavengers, and nothing was observed to indicate that they were in any way injurious to sound larvæ or pupæ. They seem to thrive equally well on putrid vegetable matter. Coquillett (*8*) mentions rearing the latter of the two species from the same situation many years earlier.

OTHER ENEMIES.

A somewhat peculiar catastrophe was found to happen very often to the larvæ which had prepared their pupation chambers in the upper end of the petioles of the floating leaves. Some animal, evidently, took a bite out of the side of the petiole close under the leaf, thereby cutting into the cavity and its occupant. In some such cases the cut-out portion of the petiole was left hanging, in others it was gone, and often the predator had bitten the petiole entirely off at this point. No portion of the larvæ or pupæ was ever found in the cavity, and the work was very evidently done intentionally in search for the insect. Often uninfested petioles were cut, evidently by mistake. The possible authors of the work were (1) ducks, a small flock of which frequented the pond; (2) frogs, of which there were many, some of them very large; (3) fishes; and (4) turtles. The character of the work eliminates the ducks and frogs because their jaws are not sufficiently strong to make such clean cuts as these were. No direct evidence of the presence of fish was found, and in such

a pond it would not be usual to find fish capable of doing such work. There remain the turtles, whose heads were frequently seen above the water. The authors were unable to capture any to examine their stomach contents, but by elimination they appear to be the most probable authors of the mischief. Doctor Welch writes that he observed nothing of the kind in Lake Erie. The effect of the work of this depredator was a substantial reduction in the number of larvæ reaching maturity.

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PORTLAND CEMENT CONCRETE ROADS.

By JAMES T. VOSHELL, *District Engineer*, and R. E. TOMS, *Senior Highway Engineer, Bureau of Public Roads.*

CONTENTS.

INTRODUCTION.

The purpose of this bulletin is to supply reliable information on the subject of concrete pavements for the use of highway engineers and others interested in the improvement of public roads. The methods of construction described are believed to represent the best practice at this time; but, as experience and research are continually suggesting improvements, those who have charge of concrete-road con-

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struction should be careful to keep themselves informed regarding results obtained by others engaged in similar work, and by laboratory experiments.

The earliest concrete pavement in the United States of which there is reliable record was constructed at Bellefontaine, Ohio, in 1893 and 1894. This pavement, which contains 4.400 square yards, was constructed in two courses and in squares similar to those employed in concrete-sidewalk construction. Prior to 1909 the total area of concrete pavements was comparatively small, and in most cases these pavements were frankly regarded as experiments. During 1909 the road officials of several communities concluded that the results already obtained were sufficiently encouraging to warrant them in undertaking the construction of concrete pavements on a larger scale, and since that time a large mileage has been completed. Wayne County, Mich., was one of the first communities to adopt this form of construction, and at present probably has a greater mileage of roads paved with concrete than any other county in the United States.

The majority of the concrete pavements which have been constructed have proved entirely satisfactory where traffic conditions were not unduly severe, and their use has increased rapidly. This is evidenced by the following tabulation, showing the approximate number of square yards of such pavements that have been placed under contract in the United States each year beginning with 1909, and the total constructed prior to 1909:

Concrete pavement constructed or under contract in the United States.

Year.	Roads.	Streets.	Alleys.	Totals.
	Sq. Yds.	*Sq. Yds.*	*Sq. Yds.*	*Sq. Yds.*
Prior to 1909	34, 061	444, 864	112, 491	591, 416
1909	32, 626	325, 158	86, 825	444, 609
1910	151, 148	682, 637	107, 874	941, 659
1911	291, 077	1, 011, 440	136, 674	1, 439, 191
1912	1, 869, 486	3, 326, 029	185, 703	5, 381, 218
1913	3, 339, 185	3, 946, 219	308, 365	7, 593, 769
1914	10, 608, 421	4, 830, 604	300, 138	15, 739, 163
1915	12, 050, 909	5, 933, 879	612, 921	18, 575, 709
1916	15, 906, 801	7, 395, 975	880, 179	24, 182, 955
1917	15, 333, 087	5, 238, 062	1, 200, 030	21, 771, 179
1918	12, 990, 519	3, 295, 817	585, 948	16, 872, 284
1919	41, 335, 342	11, 086, 419	1, 038, 173	53, 459, 934
1920	29, 326, 689	8, 814, 782	907, 164	39, 048, 635
Total to Jan. 1, 1921	143, 269, 351	56, 331, 885	6, 465, 485	206, 063, 721

The principal advantages which concrete pavements possess may be briefly stated and commented upon as follows:

1. As far as can be judged, they are durable under ordinary suburban and rural traffic conditions.

2. They present a smooth, even surface, which offers very little resistance to traffic.

3. They are practically dustless and may be easily cleaned.

4. They may be maintained at comparatively small cost.

5. They may be made to serve as a base for some other type of surface when resurfacing becomes necessary.

The principal disadvantages are:

1. They are somewhat noisy under steel-tired traffic.

2. They are subject to cracking, and wherever a crack develops it must be given frequent attention in order to prevent deterioration of the pavement.

3. On account of the sharp line of separation between the pavement and the shoulders and the marked difference in hardness, an abrupt and dangerous depression is sometimes formed at the edge of the pavement which reduces the effective width of the roadway.

A finished concrete road is shown in Figure 1, Plate X.

MATERIALS USED IN CONCRETE ROADS.

Concrete consists of a mixture of water, cement, sand, and gravel or stone or other similar materials. It is customary to refer to the sand as the fine aggregate, and to the gravel or stone as the coarse aggregate. Durable, clean, well-graded aggregates are absolutely essential to the success of a concrete pavement. Mixed aggregates, such as bank-run gravel or crusher-run stone, should not be used except under rigid laboratory control. For a successful concrete pavement, each of the different aggregates should be properly graded and kept clean and separate until proportioned to place in the mixer.

CEMENT.

Portland cement of a character satisfactory for use in pavement construction is at present manufactured in nearly every section of the country. The product of all cement plants is not always entirely uniform and of equal excellence, and even if it were uniform immediately after manufacture this condition might easily be changed by age or exposure. These facts make it imperative that cement for use in concrete pavements be subjected to very rigid tests. It should meet the requirements of the specification for Portland cement contained in Circular 33 of the United States Bureau of Standards and also issued by the American Society for Testing Materials, and accepted generally as the standard specification.

FINE AGGREGATE.

Sand is almost universally used as a fine aggregate for concrete pavements. In exceptional cases stone screenings have been used, but the use of screenings is not recommended, as the presence of dust

in the screenings makes the proper mixing rather difficult and reduces the strength of the concrete, unless the time of mixing is considerably increased. Sand for use in concrete pavements should be selected with especial care. The strength of the mortar depends largely upon the quality of the sand and a strong mortar is imperative if the best results are to be obtained. Preference should be given to sand composed of a mixture of coarse and fine grains, with the coarse grains predominating, though sand consisting entirely of coarse grains is preferable to that in which the fine grains predominate. Sand which contains more than 3 per cent of foreign materials, such as clay or silt, or the grains of which are coated with clay or other objectionable material, should not be used. Sand which contains even a small percentage of organic impurities is unsuitable because the presence of such impurities seriously affects the strength of the concrete. The presence of these impurities can not be detected by the eye but may be readily detected by means of the recently developed colorimetric test,[1] which is suitable for use in the field. In order that the mortar may develop the necessary strength, it is usually specified that mortar made from the sand proposed for use in the concrete pavement shall develop a tensile or compressive strength equal to that developed by mortar made of the same cement and standard Ottawa sand when mixed in the same proportions and tested at the same age.

It is generally specified that fine aggregate for concrete pavements shall consist of particles smaller than one-quarter inch in size. A well graded fine aggregate should meet the following requirements:

	Per cent.
Passing a ¼-inch screen	100
Passing a ¼-inch screen and retained on a standard No. 10 sieve	5–25
Passing a standard No. 10 sieve and retained on a standard No. 50 sieve	50–90
Passing a standard No. 100 sieve, not more than	10
Weight removed by elutriation, not more than	3

COARSE AGGREGATE.

Coarse aggregate for concrete pavements usually consists of gravel or crushed stone, although occasionally blast-furnace slag is used. The choice between these materials depends largely upon local conditions. Satisfactory concrete pavements have been constructed with each, but so far as cracks are concerned limestone appears to have made a better record than gravel or any other variety of stone which has been used to any considerable extent.

[1] For a description of this test see U. S. Department of Agriculture Bulletin 949, Standard and Tentative Methods of Sampling and Testing Highway Materials.

The coarse aggregate, whether crushed stone, gravel, or slag, should possess at least as great resistance to wear as the mortar which fills the voids of the aggregate. Any sound stone or gravel, moderately hard and tough, will meet this requirement, but in general the harder and tougher the coarse aggregate, the greater will be the resistance to wear offered by the concrete. The best available stone should always be used.

The difficulties experienced in securing coarse aggregate of satisfactory quality are frequently caused by a lack of proper facilities for preparing the natural materials available. Very few gravel pits furnish a gravel suitable for use in concrete pavements without washing; and properly equipped washing plants are both difficult and expensive to construct. On the other hand, a great many stone quarries contain pockets of clay or inferior stone which should not be permitted in the aggregate, and it is sometimes very difficult to remove the objectionable materials while the stone is being crushed and screened. It is also frequently difficult to screen out the dust formed in crushing some varieties of stone. These difficulties can be largely overcome by obtaining the coarse aggregate from commercial sources that are properly equipped to supply clean, well-graded aggregates.

The coarse aggregate should be free from shale, slate, coal, ocher, or other materials which easily disintegrate and should meet the following requirements:

Stone: French coefficient of wear, not less than 7.

Gravel: When subjected to the abrasion test as described in Bulletin 555, United States Department of Agriculture, page 30, the loss by abrasion should not be more than 12 per cent.

Slag: The slag should be an approved blast-furnace product, weighing not less than 80 pounds per cubic foot.

A well-graded coarse aggregate is necessary in order that the percentage of voids may be as small as practicable. The grading of the coarse aggregate is usually accomplished by specifying the various percentages of material which will pass or be retained on screens with circular openings of different sizes. The maximum size of aggregate used varies according to the practice of various States and the character of materials available. The maximum size most commonly specified is 2½ inches. A well-graded coarse aggregate should meet the following requirements:

	Per cent.
Passing 2-inch screen	100
Passing a 2-inch screen and retained on a 1-inch screen	25–60
Passing ¼-inch screen, not more than	10

WATER.

Water used in mixing concrete should be practically free from oil, acid, alkali, or organic matter and reasonably clear. Brackish water

and water carrying sewage or manufacturing wastes should not be used until tests have shown that it will not impair the strength of the concrete. For a description of a test to determine the quality of water, see United States Department of Agriculture Bulletin 949.

REINFORCEMENT.

Wire mesh, expanded metal, or steel rods may be used to reinforce the pavement. In any case the reinforcement should be reasonably free from rust or other coatings, and should be so handled prior to use that it will not be coated with mud or clay when placed in the pavement.

PROPORTIONING.

The physical characteristics of the concrete are determined not only by the quality of the several materials which enter into it, but also, and perhaps to a greater degree, by the proportions in which the materials are mixed, especially by the amount of water used. A number of theories are offered concerning the proportions required to produce strong and economical concrete. All are based on experimental data, but at present no particular one is generally accepted, and a great deal of investigation is being carried on in the attempt to evolve a theory which will be generally acceptable.

The theory most generally accepted in the past is called the maximum density theory[2] and is based on the assumption that with a given amount of cement the strongest concrete is secured with aggregates graded and mixed so as to have the least amount of voids, without an excess of fine material. It has been found from a large number of tests that the average ratio of fine to coarse aggregate for maximum density is approximately 1 to 2, a fact which accounts for the rule-of-thumb mixes, as, for example, the 1:2:4 mix, which means 1 part of cement to 2 parts of sand and 4 parts of coarse aggregate. If greater strength is required a 1:1½:3 mix is used; if less strength is needed the proportions 1:2½:5 or 1:3:6 may be adopted, but the practice is to maintain the ratio of 1 to 2 between the volumes of the two aggregates. A large amount of concrete has been mixed according to these rules, but objection is made to them on the ground that the particular aggregates used may differ materially from the average. Good aggregate and cement mixed according to the maximum density theory with a proper amount of water will produce a good concrete, but the theory itself does not take into account the amount of water to be used. Lately the amount of water has been found to exert a most important influence on the strength of the concrete. Excess, it has been found, invariably brings about a decrease in strength.

[2] "Concrete, Plain and Reinforced," by Taylor and Thompson.

The theory[3] has recently been advanced that the strength of the concrete depends entirely on the ratio of the amount of water to the amount of cement so long as the mix is workable. According to this theory variation in the grading of the aggregates affects the strength of the concrete made with a given amount of cement merely because it affects the amount of water that is required to produce a workable consistency. If the proportion of cement be varied to maintain a constant ratio of cement to water, any reasonable grading of aggregates can be made to yield a concrete of approximately any desired strength. An arbitrary quantity known as the "fineness modulus" is determined by sieve analysis of the aggregates and this quantity together with the maximum size of the aggregate determines the amount of cement to be used. The strength of the concrete made from the cement and aggregate in the determined proportions will depend upon the amount of water used. Tables and charts based upon experimental data supply the means for the practical application of the theory.

Another theory[4] is based on the assumption that to produce concrete of a given strength a certain amount of cement is required for each unit of surface area of the aggregate, taking into account the amount of water used in mixing. The particles are assumed to be spheres, and tables have been worked out from which the surface area of a given amount of the aggregate can be determined from the sieve analysis.

It is worthy of note that each of these theories tends to the use of well-graded aggregates and rich mixes where strong concrete is desired. They have all been evolved in the attempt to design concrete of high strength, which is needed in pavement concrete to enable the pavement to resist temperature and impact stresses without excessive cracking. That concrete high in compressive strength is also highly resistant to abrasion is the conclusion drawn from tests conducted by Prof. Duff A. Abrams, Lewis Institute, Chicago. It was observed in these tests that the resistance to abrasion fell off sharply when the compressive strength dropped below 3,000 pounds per square inch. The tests conducted by the Bureau of Public Roads do not support this conclusion, but indicate, rather, that the amount of wear of the concrete depends upon the character of the coarse aggregate. It should be noted that in the tests conducted by Professor Abrams only two kinds of coarse aggregate were used. For any given coarse aggregate, however, it is likely that increase in compressive strength will result in corresponding decrease in wear. From experience it has been found that pavement concrete should be proportioned to have a compressive strength of not less than 3,000

[3] Bulletin 1, Structural Materials Research Laboratory, Lewis Institute, Chicago.
[4] Proceedings of the A. S. T. M. for 1918, pt. 2, p. 236.

pounds per square inch. Pavements composed of concrete of less strength have generally proved unsatisfactory.

In practice it is generally not feasible to follow strictly any of the theories in the proportioning of the materials. The aggregates must usually be obtained from commercial sources and the specified grading of these aggregates must be such that they can be supplied without excessive expense or decreased output. The maximum size usually specified ranges from 1½ to 2½ inches. When the 2½-inch size is permitted it is usually provided that 90 to 95 per cent of the aggregate shall pass a 2-inch circular opening. For sand graded as described on page 4 and a coarse aggregate, well graded from ¼ inch to 1½ inches, the proper proportions for concrete pavements would be 1 part of cement to 2 parts of fine aggregate to 3 parts of coarse aggregate. For coarse aggregate from ¼ inch to 2½ inches in size, a proportion of 1:2:3½ or even 1:2:4 may be used provided there is sufficient mortar to finish the concrete properly. These proportions may have to be altered slightly, but for good commercial aggregate graded as described on page 5 the proportions given will prove satisfactory. Where it is not possible to obtain commercially graded aggregates of the sizes mentioned, different proportions of aggregate should be used. The following table,[5] which gives a large number of proportions designed to produce concrete of approximately 3,000 pounds compressive strength at 28 days when mixed with the water necessary to give a workable consistency, indicates the great variety of combinations that can be used.

Abrams's table of proportions and quantities for one cubic yard of concrete.

[Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6 by 12-inch cylinders, 3,000 pounds per square inch.]

Cement in barrels, aggregates in cubic yards.

Coarse aggregates.	Fine aggregates, screen openings per inch.														
	0–28			0–14			0–8			0–4			0–⅜ in.		
Size, inches.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.
No. 4 screen to ¾:															
Proportions	1	1.3	2.4	1	1.6	2.4	1	1.8	2.3	1	2.0	[illegible]	1	2.7	1.5
Quantities	1.96	.37	.69	1.85	.44	.66	1.82	.48	.62	1.75	.52	[illegible]	1.79	.72	.40
No. 4 screen to 1:															
Proportions	1	1.3	2.7	1	1.6	2.6	1	1.8	2.6	1	2.0	2.5	1	2.6	1.8
Quantities	1.90	.36	.76	1.77	.42	.68	1.72	.46	.66	1.67	.50	.62	1.72	.66	.46
No. 4 screen to 1½:															
Proportions	1	1.2	3.1	1	1.6	3.2	1	1.7	3.1	1	2.0	3.0	1	2.4	2.4
Quantities	1.82	.32	.84	1.68	.40	.79	1.63	.41	.75	1.61	.47	.72	1.62	.57	.57
No. 4 screen to 2:															
Proportions	1	1.2	3.5	1	1.5	3.5	1	1.6	3.7	1	1.9	3.6	1	2.2	3.1
Quantities	1.75	.31	.90	1.68	.36	.85	1.55	.36	.85	1.52	.43	.81	1.53	.55	.79

[5] Table prepared by A. N. Johnson, based on results of investigations by Prof. D. A. Abrams, Structural Materials Research Laboratory, Lewis Institute, Chicago, Ill.

Abrams's table of proportions and quantities for one cubic yard of concrete—Continued.

Coarse aggregates.	Fine aggregates, screen openings per inch.														
	0–28			0–14			0–8			0–4			0–⅜ in.		
Size, inches.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.
No. 4 screen to 2½:															
Proportions	1	1.1	3.8	1	1.4	3.9	1	1.6	4.0	1	1.8	4.0	1	2.1	3.5
Quantities	1.72	.28	.97	1.58	.33	.91	1.51	.35	.89	1.49	.40	.88	1.50	.46	.78
No. 4 screen to 3:															
Proportions	1	1.1	3.9	1	1.4	4.1	1	1.5	4.1	1	1.7	4.1	1	2.0	3.7
Quantities	1.69	.28	.97	1.58	.33	.97	1.49	.33	.90	1.49	.37	.90	1.49	.44	.81
⅜ to ¾:															
Proportions	1	1.3	2.3	1	1.7	2.3	1	1.9	2.3	1	2.2	2.2	1	2.8	1.4
Quantities	1.96	.37	.67	1.85	.46	.63	1.82	.51	.62	1.75	.57	.57	1.79	.75	.37
⅜ to 1:															
Proportions	1	1.3	2.6	1	1.7	2.6	1	1.9	2.5	1	2.2	2.4	1	2.7	1.7
Quantities	1.90	.36	.74	1.77	.44	.68	1.72	.48	.64	1.67	.54	.59	1.72	.68	.43
⅜ to 1½:															
Proportions	1	1.3	3.0	1	1.7	3.0	1	1.9	3.0	1	2.1	2.9	1	2.6	2.2
Quantities	1.82	.35	.80	1.68	.43	.75	1.63	.46	.73	1.61	.50	.68	1.62	.63	.53
⅜ to 2:															
Proportions	1	1.3	3.3	1	1.7	3.4	1	1.8	3.5	1	2.0	3.4	1	2.4	2.9
Quantities	1.75	.34	.86	1.63	.41	.83	1.55	.42	.80	1.52	.45	.77	1.53	.62	.66
⅜ to 2½:															
Proportions	1	1.3	3.7	1	1.6	3.7	1	1.7	3.9	1	2.0	3.8	1	2.3	3.3
Quantities	1.72	.33	.95	1.58	.37	.87	1.51	.37	.87	1.49	.44	.84	1.50	.51	.74
⅜ to 3:															
Proportions	1	1.2	3.8	1	1.6	3.9	1	1.7	4.0	1	1.9	4.0	1	2.2	3.5
Quantities	1.68	.30	.95	1.58	.37	.91	1.49	.37	.88	1.49	.42	.88	1.49	.48	.77
½ to ¾:															
Proportions	1	1.5	2.3	1	1.9	2.2	1	2.1	2.2	1	2.3	2.1	1	2.8	1.3
Quantities	1.96	.44	.67	1.85	.52	.61	1.82	.56	.59	1.75	.59	.54	1.79	.75	.34
½ to 1:															
Proportions	1	1.5	2.5	1	1.9	2.5	1	2.1	2.4	1	2.3	2.4	1	2.8	1.6
Quantities	1.90	.42	.70	1.77	.50	.66	1.72	.53	.61	1.67	.57	.59	1.72	.72	.41
½ to 1½:															
Proportions	1	1.4	2.8	1	1.9	2.9	1	2.1	2.9	1	2.2	2.8	1	2.7	2.1
Quantities	1.82	.37	.75	1.68	.47	.73	1.63	.51	.69	1.61	.52	.66	1.62	.65	.51
½ to 2:															
Proportions	1	1.4	3.3	1	1.9	3.3	1	2.0	3.4	1	2.2	3.3	1	2.7	2.7
Quantities	1.75	.36	.86	1.63	.46	.79	1.55	.46	.78	1.52	.50	.74	1.53	.62	.62
½ to 2½:															
Proportions	1	1.4	3.6	1	1.8	3.6	1	1.9	3.7	1	2.1	3.7	1	2.6	3.1
Quantities	1.72	.35	91	1.58	.43	.85	1.51	.42	.83	1.49	.46	.81	1.50	.57	.69
½ to 3:															
Proportions	1	1.3	3.7	1	1.8	3.8	1	1.8	3.9	1	2.1	4.0	1	2.4	3.3
Quantities	1.68	.33	.92	1.58	.42	.89	1.49	.40	.86	1.49	.46	.88	1.49	.53	.63
¾ to 1:															
Proportions	1	1.7	2.4	1	2.1	2.4	1	2.4	2.1	1	2.6	2.2	1	3.1	1.5
Quantities	1.90	.48	.68	1.77	.55	.63	1.72	.61	.53	1.67	.64	.55	1.72	.79	.39
¾ to 1½:															
Proportions	1	1.7	2.7	1	2.0	2.8	1	2.3	2.7	1	2.5	2.7	1	3.0	2.0
Quantities	1.82	.46	.73	1.79	.50	.70	1.63	.55	.65	1.61	.59	.64	1.62	.73	.48
¾ to 2:															
Proportions	1	1.7	3.1	1	2.0	3.1	1	2.3	3.1	1	2.5	3.0	1	3.0	2.4
Quantities	1.75	.44	.80	1.63	.48	.75	1.55	.53	.72	1.52	.56	.67	1.53	.68	.55
¾ to 2½:															
Proportions	1	1.7	3.3	1	2.0	3.5	1	2.3	3.4	1	2.4	3.4	1	2.9	2.8
Quantities	1.72	.43	.84	1.63	.47	.83	1.51	.52	.76	1.49	.53	.75	1.50	.64	.62
¾ to 3:															
Proportions	1	1.7	3.5	1	2.0	3.7	1	2.3	3.7	1	2.4	3.6	1	2.8	3.1
Quantities	1.68	.43	.88	1.58	.47	.87	1.49	.51	.81	1.49	.53	.79	1.49	.62	.68
1 to 1½:															
Proportions	1	1.7	2.8	1	2.0	2.9	1	2.3	2.7	1	2.6	2.6	1	3.1	2.0
Quantities	1.82	.46	.75	1.68	.50	.73	1.63	.55	.65	1.61	.62	.62	1.62	.75	.48
1 to 2:															
Proportions	1	1.5	3.2	1	1.9	3.5	1	2.2	3.3	1	2.4	3.3	1	3.0	2.6
Quantities	1.75	.39	.83	1.63	.46	.85	1.58	.51	.76	1.52	.54	.74	1.53	.68	.59
1 to 2½:															
Proportions	1	1.4	3.4	1	1.9	3.8	1	2.0	3.7	1	2.3	3.7	1	2.7	3.1
Quantities	1.72	.35	.86	1.58	.45	.89	1.51	.44	.83	1.49	.51	.81	1.50	.59	.69
1 to 3:															
Proportions	1	1.3	3.6	1	1.8	4.0	1	2.0	3.9	1	2.2	3.9	1	2.7	3.3
Quantities	1.67	.33	.90	1.58	.42	.94	1.49	.44	.86	1.49	.48	.86	1.49	.59	.73

QUANTITIES OF MATERIALS REQUIRED.

The quantities of materials theoretically required for concrete pavements of various proportions, thicknesses, and widths are given in the appendix, pages 61 and 62. The quantities of aggregates are given in cubic yards. To correct to an approximate tonnage basis, the fine aggregate quantities should be multiplied by one and one-half and the coarse aggregate quanties multiplied by one and one-third. In practice an allowance must also be made for waste or loss in handling these materials. This allowance should be approximately 2 per cent for cement, from 2 to 4 per cent for fine aggregate, and from 3 to 7 per cent for coarse aggregate, depending upon the method used in handling the material.

DESIGN OF CONCRETE ROADS.

There are two general types of concrete pavement, known, respectively, as one-course and two-course pavement. The former consists of one course of concrete, all of which is mixed in the same proportion and composed of the same kind of materials, while the latter consists of two courses, usually mixed in different proportions and containing different kinds of aggregate. The one-course pavement is much simpler to construct than the two-course type. For the one-course construction it is customary to employ a coarse aggregate of average wearing qualities, which can readily be obtained from commercial sources.

Where a very large volume of steel-tired traffic is anticipated, however, it is sometimes desirable to provide a surface of exceptionally good wearing quality to resist the abrasive action of this particular kind of traffic. Inasmuch as aggregates having high resistance to wear, such as granite and trap, frequently have to be imported from long distances at great cost, the cost of a road composed entirely of this aggregate would be almost prohibitive. This has led to the development of the two-course type of construction in which local coarse aggregate of average or low wearing qualities is used in the lower course and imported aggregate with high resistance to wear is used in the top course. For example, if the only materials locally available for use as aggregate are of inferior quality, it would usually be more economical to use them for aggregate in the lower course of a two-course pavement and import aggregate for the wearing course than to employ a one-course pavement and import all the aggregate. The coarse aggregate in the top course is somewhat smaller than in one-course construction and the thickness of the top course is usually about 2 inches.

In the two-course construction it has been somewhat general practice to permit leaner proportions for the lower course than would

be required for one-course construction, but it is not believed that this practice is justifiable unless the thickness is correspondingly increased. With the development of modern traffic, the load-carrying capacity of the pavement is an important consideration, and the requirements of strength should govern the proportions of the lower course in two-course construction to the same extent as in one-course construction. The construction of a two-course pavement involves construction difficulties in mixing and handling two kinds of concrete and usually in securing two kinds of coarse aggregate, especially if one kind is shipped by rail, and therefore usually costs correspondingly more to build than the one-course pavement.

Under modern traffic conditions the amount of abrasive traffic on main roads is rapidly decreasing and observations of concrete pavements built with aggregates of average wearing qualities that have been in service from 6 to 8 years fail to show any serious wear from abrasion. Except under unusual conditions, therefore, it would not appear necessary to resort to two-course construction.

Besides the two general types of concrete pavement described above, there are several patented types, but so far as is known these do not possess any particular advantages and will not be discussed in detail. The one-course pavement is believed to be better adapted to most ordinary conditions than any other type of concrete pavement and will be principally considered in the following discussion.

WIDTH OF PAVEMENT.

The width of pavement necessary will depend upon the frequency with which vehicles are expected to pass each other, the character of the vehicles, and their speed. For single-track roadways a width of 10 feet is usually adopted. This width is ample for a single line of traffic, but passing vehicles will be forced to use the shoulders of the road which consequently will require considerable maintenance. The frequency with which vehicles pass each other has made it necessary in some instances to construct shoulders of broken stone or gravel.

It is believed that all trunk-line roads and roads of primary State systems should be constructed to accommodate two lines of traffic, whether the necessity for such a width exists at the time of construction or not. The history of highway improvement shows that there is always a tremendous increase in traffic upon the completion of the improvement. This potential increase usually justifies the double-track road. Where funds are the controlling factor in the construction of the primary system, it may be desirable to construct a single-track pavement in certain sections and make provision for widening the pavement at a later date when the volume of traffic justifies the expense. In doing this the road should be graded the

necessary width for a double-track pavement and a 9-foot pavement built to one side of the center line of the grade. In widening a pavement of this type to 18 feet it would only be necessary to lay a slab 9 feet in width adjacent to the original slab. A typical cross-section for a pavement of this type is shown in Figure 7, page 28.

The character of vehicles, together with the clearance necessary for safety in passing, will largely determine the width of pavements for double-track roads. Motor-truck traffic has grown to such proportions that it has been necessary in many States to limit by statute the size of load and the total width of body. The maximum width of truck body generally permitted is 8 feet. If ample clearance is provided for the passing of trucks of maximum size a desirable factor of safety will be provided for smaller trucks and passenger motor vehicles. For slow-speed traffic, such as truck traffic, a clearance of 3 to 3½ feet is necessary for safety, while for high speed traffic, such as automobiles, a clearance of at least 5 feet should be provided. The amount of truck traffic is small, in comparison to automobile traffic, except in the neighborhood of large cities, so that the frequency with which one truck passes another is almost neglible in comparison with the frequency with which automobiles pass trucks. If, therefore, ample clearance is allowed for the passage of an automobile and a truck, the maximum of safety will be obtained at the minimum of cost.

The diagram, Figure 1, shows the width of pavement necessary for reasonable clearance for trucks passing each other and for an automobile passing a truck. At an average speed of 30 miles per hour it is unreasonable to expect the driver of an automobile to drive with the wheels closer than 1½ feet to the edge of the pavement. For trucks at an average speed of 15 miles per hour, this distance should not be less than 1¾ feet on account of the great width of the rear wheel. Inasmuch as a certain amount of truck traffic is to be expected on all main country roads, the minimum width of pavement for this class of road should be 18 feet. Where the frequency with which trucks pass each other becomes a big factor, as in the neighborhood of large cities, the minimum width of pavement should be 20 feet.

THICKNESS OF PAVEMENT.

The determination of the proper thickness of a concrete pavement for different kinds of traffic is a very complex problem in applied mechanics, and depends to a large extent on certain factors which at present are more or less indeterminate. In the first place, the loads acting on a pavement are not merely static loads, but are applied with considerable impact. This impact varies with the roughness of the

pavement, the speed of the vehicle, the character of the tires, and the percentage of the total load which is carried above the springs of the vehicle. Under very unfavorable conditions it may be as high as five times the amount of the static load.

The pavement itself depends upon the subgrade for support, and this support is extremely nonuniform in character. The supporting power of a subgrade depends upon the type of soil, its capillarity, the

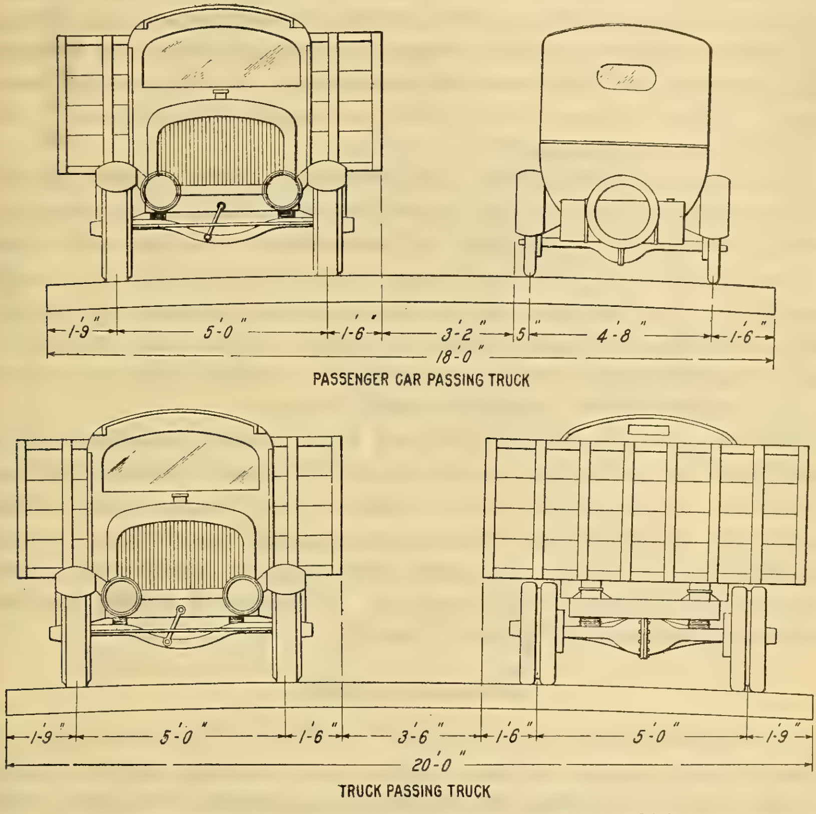


FIG. 1.—Width of road required for safe passage of vehicles.

proximity of ground water, the condition of surface drainage, the amount of sustained rainfall, and the extent of freezing and thawing.

All of these factors are extremely variable, and in combination are almost indeterminate, so that it is almost impossible to reduce the determination of pavement thickness to a simple mathematical computation. The behavior of concrete pavements of known thickness under known soil conditions and known conditions of traffic is the most satisfactory index of the thickness of pavement required.

It has been more or less customary in the past to use a flat subgrade for concrete pavements, and obtain the necessary crown in the pave-

ment by making the concrete thicker at the center than at the sides. The flat subgrade was adopted originally, no doubt, for the reason that it was simpler to construct than any other form. For a double-track pavement, however, where two lines of traffic are accommodated, the use of a flat subgrade imposes the maximum wheel load on practically the thinnest part of the pavement. Under heavy traffic conditions this has often led to complete breakdowns of the edges of the pavement. This action is greatly accentuated where diagonal transverse cracks occur. For a double-track pavement where the volume of traffic confines the limits of travel in each direction, it is essential that the edges be of the same thickness as the remainder of the pavement. This can be secured by using a crowned subgrade and a uniform thickness of pavement.

On a sandy or sandy-loam soil, where the traffic consists mainly of horse-drawn vehicles and passenger automobiles, with comparatively few trucks, a thickness of pavement of 6 inches will often prove satisfactory. As the volume of truck traffic and the weight per truck load increase, the pavement should be made correspondingly thicker. A greater thickness should also be used on soils of poor bearing quality which are difficult to drain than on soils of good bearing quality which are easily drained.

For the average condition of soil under traffic conditions up to and including 150 trucks per day, a thickness of 8 inches is believed desirable. In the neighborhood of large cities where a large volume of heavily loaded truck traffic is to be expected, the thickness should preferably be 9 inches, and under very unusual conditions a thickness of 10 inches may be necessary. A failure of a thin concrete pavement is shown in Figure 2, Plate X.

CROWN OF PAVEMENT.

A concrete pavement lends itself readily to the construction of low crowns. A low-crowned road is very desirable for the traffic. Water does not damage the surface of a concrete road and under present traffic conditions the wear of the surface is comparatively small, so the necessity for a high crown does not exist in this type. The amount of crown need not be any more than is necessary to shed the water from the surface, taking into consideration the small imperfections and depressions which exist in it. A crown of one-eighth to one-fourth inch per foot is sufficient. In the operations of finishing a concrete pavement surface a slight amount of crown will be lost, so that if the tamper is cut to a true 2-inch crown, the resulting crown in the pavement will closely approximate $1\frac{3}{4}$ inches. This fact should be taken into consideration in specifying the amount

of crown. The crown of a pavement may be either an arc of a circle or a parabolic curve. In road construction it is generally customary to make it an arc of a circle.

SUPERELEVATION OF CURVES.

For modern traffic it is becoming customary and desirable to superelevate pavements on all curves. Superelevation of pavements compensates centrifugal force, reduces the danger of skidding on curves, and induces traffic to keep to the right side of the road. The amount of superelevation necessary will depend upon the radius of the curve and the speed of the traffic, but under no circumstances

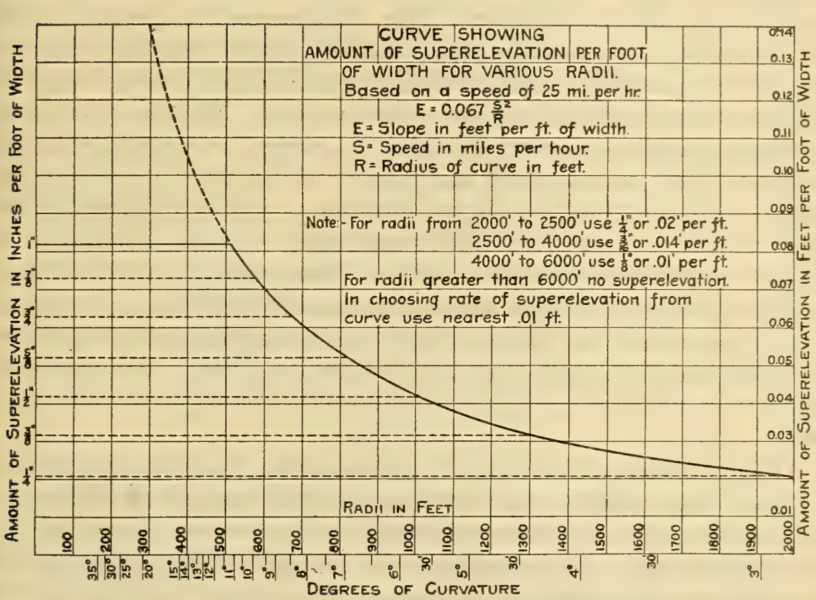


FIG. 2.—Curve showing superelevation per foot for curves of various radii.

should it be so great as to be objectionable or dangerous to horse-drawn traffic. The maximum superelevation for this latter class of traffic should not exceed 1 inch per foot of width. The speed of other vehicles on curves of short radius must therefore be reduced to conform to this superelevation. If this maximum be adopted, the amount of superelevation for the various radii of curvature may be easily computed. The curve, Figure 2, shows the amount of superelevation per foot of width for curves of various radii and a superelevated curve is shown in Figure 2, Plate IX.

Superelevation may be accomplished by rotating the pavement about its central axis, i. e., lowering the inner edge of the pavement and raising the outer edge. If drainage conditions will not permit

the lowering of the inner edge, the superelevation may be obtained by rotating the pavement about the inner edge, i. e., by raising the outside of the pavement. The maximum superelevation should be obtained at the point of curve and continued for the entire length of the curve. The pavement should begin to gain superelevation at a point on the tangent approximately 100 feet from the beginning of the curve, reach a maximum at the point of curve, and ease off to the regular pavement cross section the same distance beyond the point of tangency.

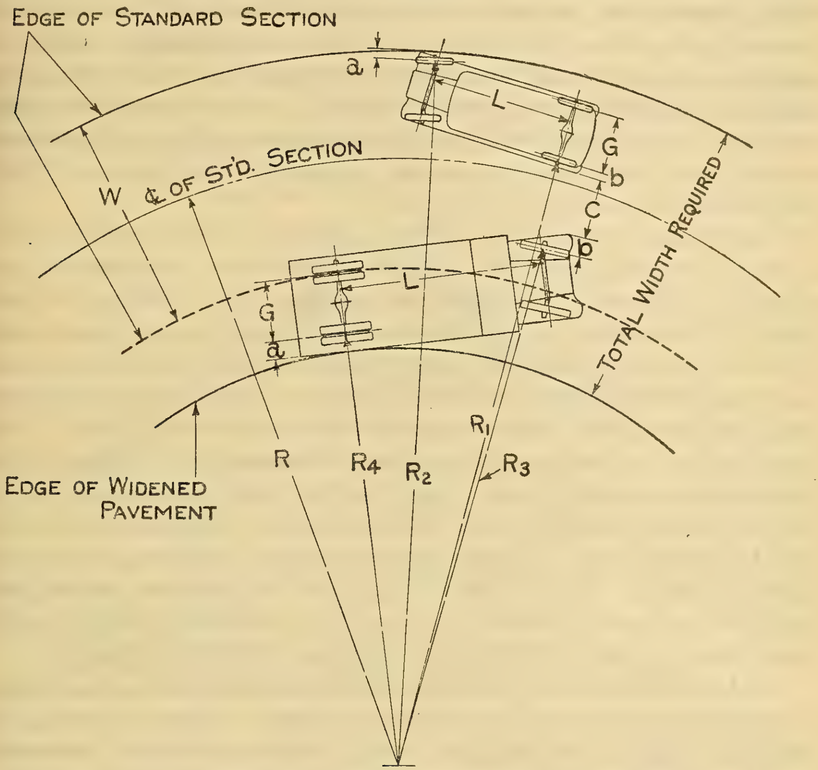
WIDENING ON CURVES.

In rounding a curve the rear wheels of a vehicle travel on a shorter radius than the front wheels. On this account a greater width of pavement is occupied by the vehicle on curves than on tangents. The additional width varies with the radius of the curve, the gauge of the wheels and the length of the vehicle. To allow the same clearance between passing vehicles on curves as on tangents the width of the pavement on the curves should be increased by an amount equal to the sum of the additional widths required by the two vehicles. If two vehicles of maximum size are assumed, i. e., trucks of 204-inch wheel base with a 5-foot gauge, it will be found that for curves of 30-foot radius the amount of widening required is 12.5 feet, while for curves of 150-foot radius the additional width is 2 feet and for a radius of 500 feet, only 0.5 foot. For curves of more than 500-feet radius the additional width required is negligible.

If the passing vehicles are two automobiles of averge size instead of two large trucks the additional width required will be less on account of the shorter wheelbase and narrower gauge of the smaller vehicles. If provision is to be made for the passage of a truck and an automobile the extra width required will be between the larger and the smaller amount. In widening curves the added width should be consistent with the provision that has been made on tangents. If the normal section on tangents is 16 feet wide the road will accommodate two automobiles in passing and the additional width on curves should be designed to provide for two such vehicles. The 18-foot normal section provides for the passage of an automobile and a truck, and the 20-foot section accommodates two large trucks. The additional width on curves, therefore, should provide for the passage of vehicles of the same type. The method of computing the amount of widening required is illustrated in Figure 3.

Theoretically the amount of widening determined in this manner is all that is required, but an additional allowance of a foot or two

is generally made to allow greater clearance between the passing vehicles on curves for additional safety. As the clearance allowed



R = Radius of Center of Standard Section of Pavement.
W = Width of Standard Section of Pavement.
a = Distance from Edge of Pavement to Center of Nearest Wheel (taken as $1\frac{1}{2}$ ft. for Passenger Cars and $1\frac{3}{4}$ ft. for Trucks).
C = Clearance between Vehicles.
L = Length of Wheel Base of Vehicles (taken as 12 ft. for Passenger Car and 17 ft. for Truck).
G = Gauge of Vehicles (taken as $4\frac{2}{3}$ ft. for Passenger Car and 5 ft. for Truck).
b = Width of Vehicles overhanging Wheels (taken as $\frac{1}{2}$ ft. for Passenger Car and $1\frac{1}{2}$ ft. for Truck).

$R_2 = R + \frac{1}{2}W - a.$ $\quad (R_1 + G)^2 = R_2^2 - L^2.$ $\quad R_1 + G = \sqrt{R_2^2 - L^2}.$

$R_1 = \sqrt{R_2^2 - L^2} - G.$ $\quad R_3 = R_1 - (C + 2b).$ $\quad (R_4 + G)^2 = R_3^2 - L^2.$

$R_4 + G = \sqrt{R_3^2 - L^2}.$ $\quad R_4 = \sqrt{R_3^2 - L^2} - G.$ $\quad$ Total Width Required $= R - R_4 + a + \frac{1}{2}W.$

FIG. 3.—Method of computing amount of widening on curves.

on the tangents is from 3 to $3\frac{1}{2}$ feet, it is believed that a minimum of 5 feet should be provided on the curves.

The table on page 19 gives the amount of widening for curves of 16, 18, and 20 foot pavements, computed on the basis of the above assumptions for curves up to 500-foot radius. For curves of greater radius than 500 feet the amount of widening would be practically constant and would be based upon the greater clearance required on curves for additional safety. At what point widening should be discontinued is somewhat problematical, but it is believed no additional clearance in passing is required for curves of 1,000 feet radius or greater.

It is now generally agreed that the increased width should be added to the inside rather than the outside of the curve; but there is considerable difference of opinion as to where the widening should begin. If the path of a vehicle around a circular curve is analyzed, it will be found that as the front wheels conform to the curve, the rear wheels effect a gradual transition to concentric curves of shorter radii and then follow these concentric curves around the circle. This transition of the rear wheels to curves of shorter radii begins on the tangent approximately one vehicle length from the point of curve and is generally completed in from one to one and one-half vehicle lengths on the curve. The necessity for curve widening, therefore, exists practically for the entire length of the circular curve; and for curves ordinarily used in highway practice, full widening should obtain both at the point of curve and the point of tangency.

The logical method of widening curves, therefore, is on the inside, full amount of widening for the entire length of circular curve. To gain this width at the two ends of the circular curve it is necessary that the widening of the pavement be begun at some distance from the points of curvature and tangency, thus providing a widening approach section to the curve. Theoretically, the length of this approach section should be varied with the degree of the curve, but in practice it is customary to employ a uniform length for all curves. A simple design which has proved satisfactory is shown in Figure 4, in which the approach section is in the form of a taper and the widening is begun at a distance of 100 feet from the ends of the circular curve. Instead of a straight-line taper, a transition curve may be used. In this case the offset from the tangent to the circular curve would be equal to the amount of widening and would determine the length of transition curve which would have to be used. A transition curve, however, cannot be used on widened curves of very short radii, because the amount of widening is so great and the length of circular curve so small that a true transition curve will not satisfy the conditions. For curves of 200-foot radius and over the transition curve will give satisfactory results.

If it is desired to use transition curves to connect the circular curve and the tangents, widening may be accomplished as shown in

Figure 5. As the offset from the tangent to the inner circular curve in this case will be increased by the amount of widening required, the length of the transition to the inner edge of the pavement will always be longer than the transition used on the outer edge of the pavement. The use of transition curves will materially increase the field operations of staking out the work, but it is believed their use is desirable on curves of from 200 to 1,000 foot radius.

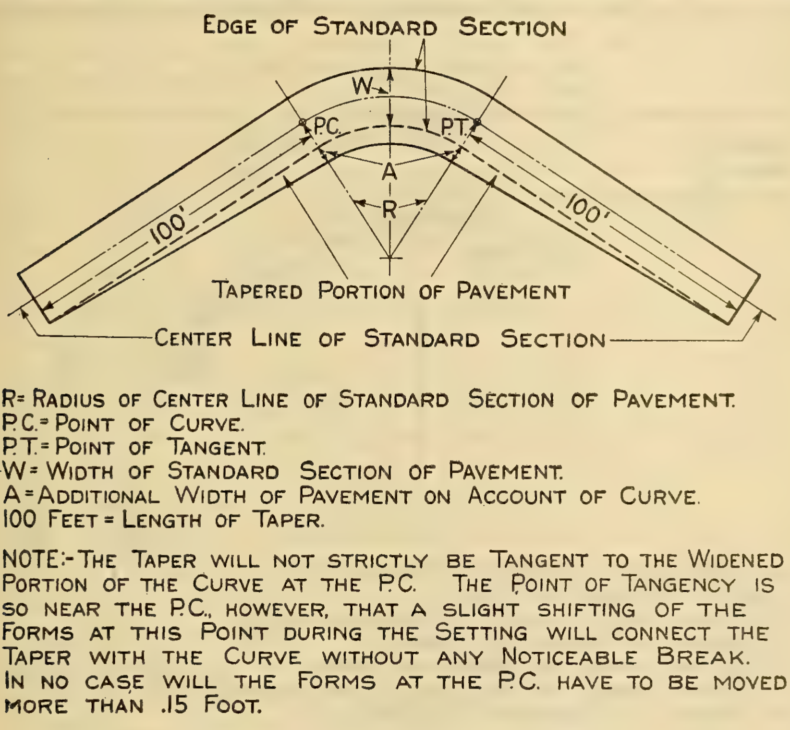


FIG. 4.—A simple method of widening curves.

Table of curve widening.

Radius of center line curve.	Additional width of pavement required for—			Radius of center line curve.	Additional width of pavement required for—		
	16-foot pavement.	18-foot pavement.	20-foot pavement.		16-foot pavement.	18-foot pavement.	20-foot pavement.
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
30	8.0	11.0	14.0	125	3.5	4.0	4.0
40	6.0	8.0	9.5	150	3.5	3.5	3.5
50	5.5	6.5	7.5	175	3.0	3.0	3.0
60	5.0	5.5	6.5	200	3.0	3.0	3 0
70	4.5	5.0	5.5	250	3.0	3.0	2.5
80	4.0	4.5	5.0	300	3.0	2.5	2.5
90	4.0	4.5	4.5	400	3.0	2.5	2.0
100	4.0	4.0	4.5	500	2.5	2.5	2.0

JOINTS.

Concrete contracts or expands with changes in temperature and differences in moisture content. It also shrinks materially during the period of setting and initial drying out. In practically all early concrete pavements transverse expansion joints were constructed 25 to 30 feet apart, with the idea of relieving the pavement slabs of all stresses due to expansion and contraction, thereby preventing transverse cracking due to tensile stresses or failures due to compressive

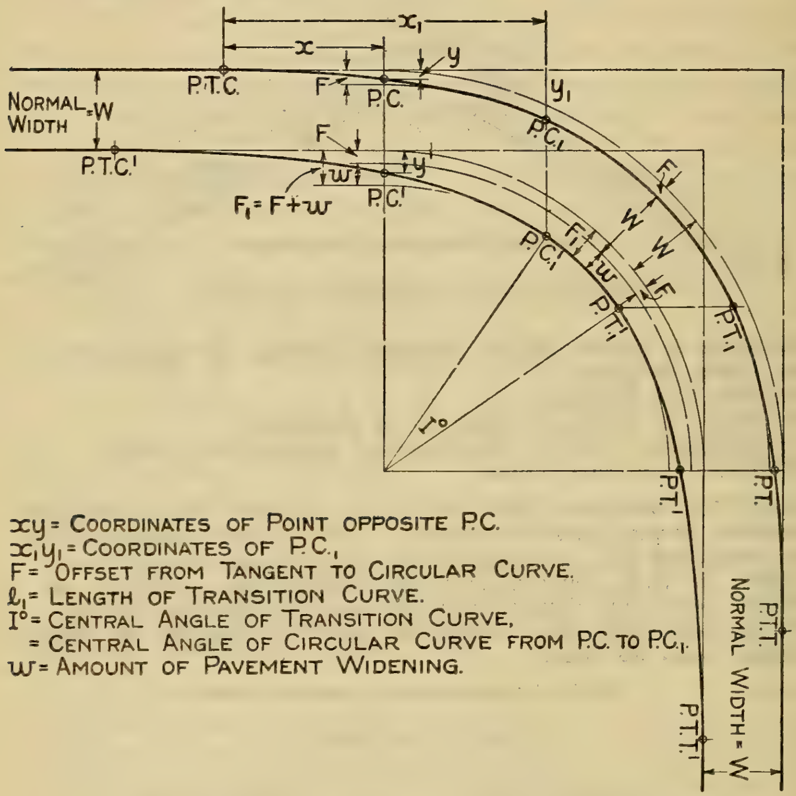


FIG. 5.—Method of widening curves using transition curves.

stresses. In these pavements it was found, however, that a majority of the slabs cracked transversely, that it was very difficult to secure a pavement with good riding qualities in the neighborhood of the joints, and that if the expansion joints were not constructed so as to be perpendicular to the surface of the pavement the end of one slab was very likely to rise above the end of the adjacent slab. Not infrequently this relative movement amounted to 2 or 3 inches and inconvenienced traffic very materially. If the joint varied from the

vertical as little as 5°, this movement was likely to occur and it was found difficult in construction work to avoid even greater variations.

These findings led to the experiment of building pavements without expansion joints, and it was found in pavements so built that the transverse cracks did not occur more frequently than in those built with expansion joints and that the shrinkage due to the setting and initial drying out of the concrete provided sufficient room for such expansion as occurred later from changes in temperature and moisture content, except in pavements laid in cold weather. In pavements laid in cold weather it appeared that the shrinkage due to setting and initial drying out did not provide sufficient space for subsequent expansion caused by changes in temperature and moisture, and local failures of the pavement were not infrequent.[6] Experience, therefore, indicates that transverse joints are unnecessary in pavements laid when the air temperature is generally above 50° F., but are necessary in pavements laid in cold weather. The majority of plain concrete pavements are now constructed without joints. Transverse cracks will occur in pavements so constructed at more or less regular intervals, averaging 30 to 50 feet apart. These cracks in general are less objectionable than joints. They do not adversely affect the riding qualities of the pavement, slipping of the slabs rarely occurs, the cost of maintaining them is no greater, and, if properly maintained, they do not materially injure the pavement.

It is customary to construct transverse joints in reinforced pavements. They are generally spaced from 40 to 80 feet apart. The method most often used in constructing transverse joints is to separate the sections of the pavement by means of specially prepared bituminous felt boards. These are usually held in place by means of properly shaped steel templates until the concrete is deposited against them, after which the templates are removed and the concrete flows around the boards. The thickness of this joint has varied in common practice from one thickness of two-ply tar paper up to about one-half inch. A thickness of one-quarter inch seems to give very satisfactory results when the joints are spaced not more than 40 feet apart. Joints of this kind are sometimes provided with metal armor, which is intended to keep the adjacent edges of the concrete from spalling off. It is claimed that armored joints require less maintenance than other types, but they are more expensive to construct. As the amount of abrasive traffic on country pavements is steadily decreasing, there does not appear to be any necessity for this type of joint except under unusual conditions.

[6] A full discussion of the expansion and contraction of concrete roads may be found in U. S. Department of Agriculture Bulletin 532.

The use of longitudinal joints along the central axis of the road has generally been confined to pavements exceeding 20 feet in width. Where such joints have been used, it has been customary to construct one-half of the pavement width at one operation. After this portion of the pavement has been completed, the remaining half portion is constructed. The edges of the longitudinal joint are rounded with an edging tool, and after curing the joint is filled with bituminous material. The method of constructing a pavement in two half sections is particularly advantageous on some heavily traveled roads where it is not possible to divert the traffic. The construction of a pavement of this type can be carried on without diverting the traffic, although the operations of the contractor are hampered somewhat, resulting in slightly increased costs.

It has not been general practice to use a longitudinal joint in the construction of pavements 16 to 20 feet wide, when the full width of pavement has been constructed at one operation, but there are several arguments in favor of this form of construction. From observation of a large mileage of concrete pavements, it is found that longitudinal cracks rarely occur in pavements 9 or 10 feet wide, but frequently occur in pavements exceeding 16 feet in width. It is reasonable to assume, therefore, that a longitudinal joint along the central axis of the pavement would practically eliminate cracking.

Longitudinal cracks are more objectionable than transverse cracks because they have a tendency to gradually increase in width. When they occur along the line of wheel traffic the edges of the cracks deteriorate rapidly unless carefully maintained. Another important advantage of a longitudinal joint along the central axis of the road is that it serves to define sharply the limits of travel in each direction, thus providing a desirable factor of safety for road travel.

A longitudinal joint for full-width pavement construction should be of the submerged type. A joint of this type usually extends from the bottom of the pavement to within approximately three-fourth inch of the surface. The purpose of the submerged joint is to facilitate and simplify the operations of striking, tamping, and finishing the surface of the pavement, which would otherwise be rather difficult with the joint extending through the pavement. A strip of 18 or 20 gauge metal, held rigidly in place by pins driven into the subgrade, will usually prove satisfactory. The metal should preferably be corrugated or deformed sheets so as to key the two sections together. Reinforcing steel should be used to tie the two sections of the pavement together and prevent any lateral movement. The reinforcing steel should be placed halfway between the top and bottom of the slab. The practice of the Illinois highway department is to use five-eighths-inch deformed bars, 5 feet long, spaced

10 feet center to center, extending an equal distance into each section of the pavement. The metal joint may either be punched or slotted to provide for the reinforcing steel. When the surface of the pavement cracks above the submerged joint, the crack is filled with bituminous material.

STEEL REINFORCEMENT.

Steel reinforcement in the past has been used in concrete pavements, primarily to prevent excessive cracking. For this purpose it has been customary to use wire mesh or expanded metal weighing from 25 to 40 pounds per hundred square feet. Equally satisfactory results, however, can be obtained by the use of ½-inch deformed bars spaced 24 inches center to center in both directions. This reinforcing should be placed not less than 2 inches from the finished surface of the pavement and should extend to within 2 inches of all joints, but not across them. Adjacent lengths of wire mesh or expanded metal should be lapped from 4 to 8 inches. For ease in handling, the wire mesh or expanded metal should be obtained in flat sheets. The use of this kind of reinforcement will add from 30 to 60 cents per square yard to the cost of the pavement and this additional cost is no doubt responsible for the fact that concrete pavements have not generally been reinforced in the past. Reinforcement of this type, moreover, does not entirely prevent cracks, but distributes them and keeps them small.

Under very severe traffic conditions and for pavements laid on exceptionally soft subgrades which cannot be materially improved, reinforcement may be necessary to give greater strength to the pavement by distributing the load over a larger area. Deformed bars should be used for this reinforcement and the percentage of reinforcement required will depend on the traffic loads, the condition of the subgrade, and the range of temperature and the variation in percentage of moisture. The reinforcement should preferably be placed both at the top and the bottom of the pavement and may vary from ½ to ¾ inch bars spaced from 18 to 24 inches center to center in both directions. Reinforcement to give added strength to the pavement is rapidly gaining favor among engineers, and it is now being extensively used in localities where a large volume of heavy traffic is to be expected.

Another form of pavement reinforcement—circumferential reinforcement—consists of ¾-inch bars, placed half way between the top and bottom of the pavement, approximately 6 inches from the edges, and completely around the slab. This form of reinforcement gives added strength at the edges where cracks usually begin, and on a soft subgrade serves to hold the pavement together should cracking occur.

SHOULDERS AND DITCHES.

The width and kind of shoulders necessary for concrete pavements will depend upon the width of pavement and the volume of traffic. On single-track pavements the shoulders must be sufficiently wide to provide for safety of passing vehicles and must be composed of material which will support them satisfactorily. On double-track pavements the shoulders should be of sufficient width to allow for irregular and unexpected actions by inexperienced drivers or frightened animals, and, where the volume of traffic is large, to permit automobiles to turn out onto the shoulders for minor adjustments or tire repairs without blocking the traveled way. The width of each shoulder, then, should be not less than 5 feet; a width of 6 or 7 feet is preferable.

It has generally been customary to construct gravel or macadam shoulders to single-track roads on clay soils. This may be accomplished by constructing gravel or macadam strips 3 feet wide on each side of the pavement, or in the case of a single-track pavement built on one side of the center line by placing the gravel or macadam strip all on one side and making the width 6 feet. These gravel or macadam strips are usually 4 to 6 inches thick. On soils of a gravelly nature which have rather good supporting power when wet, metaled shoulders are not used. A double-track road should be wide enough to permit the passing of vehicles without turning out on the shoulders, so no shoulder should be necessary for this pavement other than the natural soil.

The slope of the shoulder should be such as will readily dispose of the water, and at the same time not be so steep that it will appear dangerous to drive on. Shoulders along a low-crowned pavement should have a slope as flat as possible so as not to accentuate the change in slope. A slope of $\frac{1}{2}$ inch to 1 foot should prove satisfactory. Inasmuch as the shoulders of a concrete road are seldom rolled, some slight settlement takes place, and it is usually found that if a very flat shoulder is constructed it will have all the slope necessary after the road has been opened to traffic for a short time.

Surface ditches are usually constructed of two general shapes—the V shape, and the trapezoidal shape. In rolling country, where the surface water can be turned away from the road at frequent intervals, the V-shaped ditch has proved very satisfactory. Where it is necessary to carry water in the ditches for considerable distances the trapezoidal ditch should be used. The bottom of the ditch should be at least 18 inches lower than the center of the road; and when a large volume of water is to be carried the minimum depth should be 24 inches. The slopes to the ditches from the shoulder should not be steeper than 2 to 1.

CURBS AND GUTTERS.

To prevent erosion of the side ditches and the danger of washouts on relatively steep grades, some form of paved gutter, or combined curb and gutter, must be used. The amount of erosion depends upon the velocity of the water and the kind of soil. On soils of loose texture a small accumulation of water on grades as low as 3 per cent is sufficient to cause considerable erosion; while some soils of dense texture are not materially eroded on grades as high as 6 per cent. The grade, therefore, on which it will be necessary to use a paved gutter will depend upon the kind of soil. In general, it will be found desirable to provide paved gutters on all grades greater than 5 per cent.

A paved gutter, or the combined curb and gutter, may often be used to advantage in reducing the amount of grading in through and hillside cuts. For example, in deep cuts the amount of grading can often be reduced as much as 35 per cent by omitting the shoulders and side ditches and providing curbs along the edges of the pavement, so that the sides of the pavement serve as gutters. Similarly on heavy hillside work, by omitting the shoulder and ditch next to the hill and using a curb on one side, a considerable saving in grading can be effected. Inasmuch as the use of curbs confines traffic to the pavement, the width of the pavement should be slightly increased where curbs are employed. If curbs are used in connection with a standard 18-foot pavement with earth shoulders, the width between curbs should be at least 20 feet.

The paved gutter, or the combined curb and gutter, can be constructed as an integral part of the pavement, but this operation is a slow, tedious one which slows up the laying of the main body of the pavement and prevents the use of a mechanical finishing machine to the best advantage. Better results will be obtained if the regular width of pavement is constructed first and the gutter, or curb and gutter, constructed later. If this procedure is adopted, the gutter, or curb and gutter, should be tied to the main pavement by short pieces of reinforcing steel. This can be accomplished by drilling holes in the pavement forms midway between the top and bottom and inserting bars 3 feet long, spaced 2½ to 3 feet apart, so they will project into the pavement about one-half their length. The bars should not be bent to conform to the gutter section until the forms have been removed. Joints should be placed in the gutter, or the curb and gutter, at points where joints exist in the pavement. Typical details of circular and V-shaped gutters and a combined curb and gutter are shown in Figure 6.

BITUMINOUS SURFACE TREATMENT.

A coating of bituminous material and sand, gravel, or stone chips applied to the surface of a concrete road is known as a bituminous

surface treatment. The thickness of the coating is generally from one-fourth to three-eighths inch. Bituminous surface treatments have been used to some extent, principally because it was thought that they served to protect the concrete pavement by cushioning the

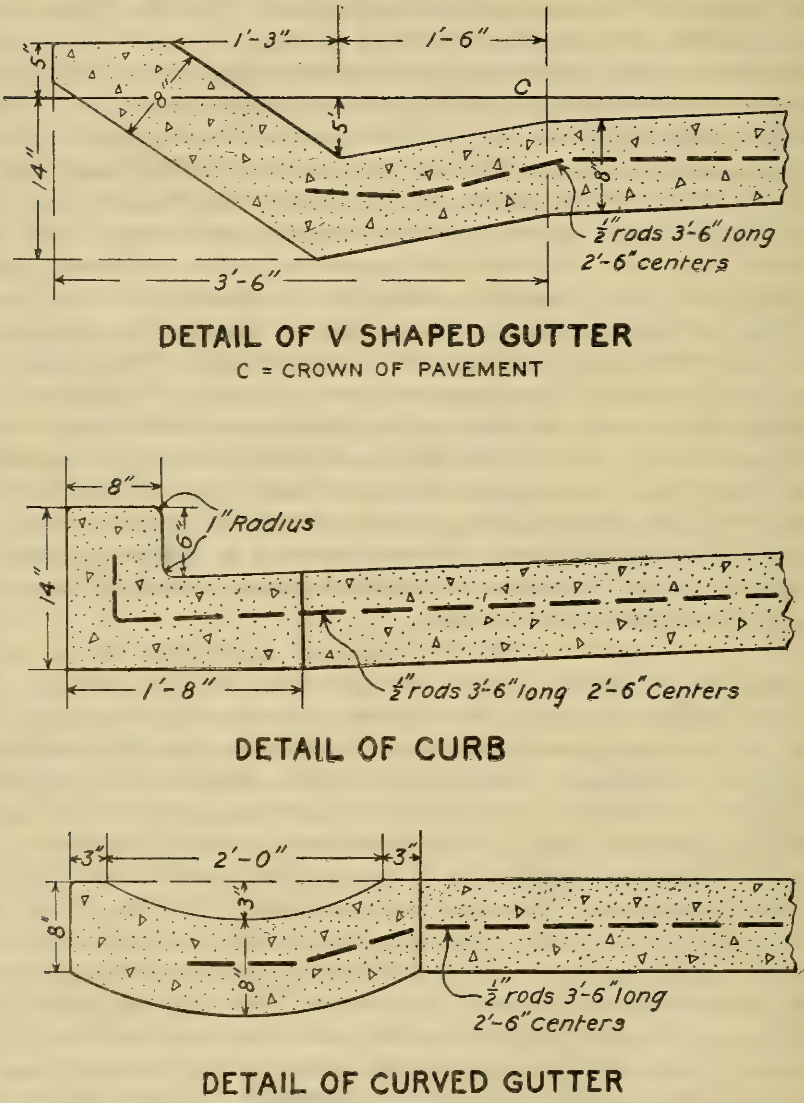


FIG. 6.—Typical details of gutter and curb.

impact of traffic and preventing the abrasion of the surface. Their use is now being generally discontinued. It is found that a bituminous surface approximately one-fourth inch thick has little, if any, cushioning value and consequently does not lessen the impact

to any appreciable extent. The amount of abrasive traffic on country roads is steadily decreasing and a well-constructed concrete pavement no longer shows any marked deterioration through abrasive action. The chief advantage of a bituminous surface treatment lies in the fact that cracks are automatically bridged over as they appear and surface water is prevented from reaching the subgrade through these cracks. The difficulty of securing proper adhesion of the bituminous surface to the concrete, its cost, and the necessity for continuous maintenance of the surface constitute its greatest disadvantages. It is believed that these disadvantages greatly outweigh any possible advantages which might be obtained through its use.

THE CROSS-SECTION.

Typical cross sections of pavements based upon the foregoing discussion of design are shown in Figure 7.

CONSTRUCTION.

GRADING.

The grading requirements for concrete pavements are essentially the same as for other types of pavement. The shoulders may either be roughly built at the time the heavy grading is done or be constructed after the pavement has been placed. If the shoulders are roughly built before the pavement is placed, frequent drainage openings must be left in them to insure the rapid drainage of the subgrade during periods of rainfall. This is very essential if the pavement operations are not to be delayed by a poor subgrade.

DRAINAGE.

Surface drainage is secured by means of the pavement crown, the slope of the shoulders to the ditches, and frequent outlets for the water from the side ditches through culverts and bridges. In addition to surface drainage, soil conditions are sometimes such as to require subdrainage. Subdrainage is usually desirable over low, swampy ground and at points where ground water is encountered on hillsides or in deep cuts. Subdrainage may be effected by the use of drain tile, laid in trenches back filled with stone, gravel, or other porous material, or by the use of V-drain foundations in which large-sized stone is used and outlets are provided at all low points in the grade. The use of a V-drain foundation or any other form of prepared porous foundation under concrete pavements serves only to lower the point of support of the pavement. A somewhat wider distribution of pressure is secured by the use of these foundations; but on soils requiring this wider distribution of pressure it is believed it can be more cheaply obtained by reinforcement than by the use of the prepared foundation. The most effective subdrainage for concrete pavements is obtained by the use of tile laid under the outer

edges of the concrete pavement, back filling the trench to the level of the bottom of the pavement with stone or gravel. Whether the tile should be used under both edges of the pavement will depend

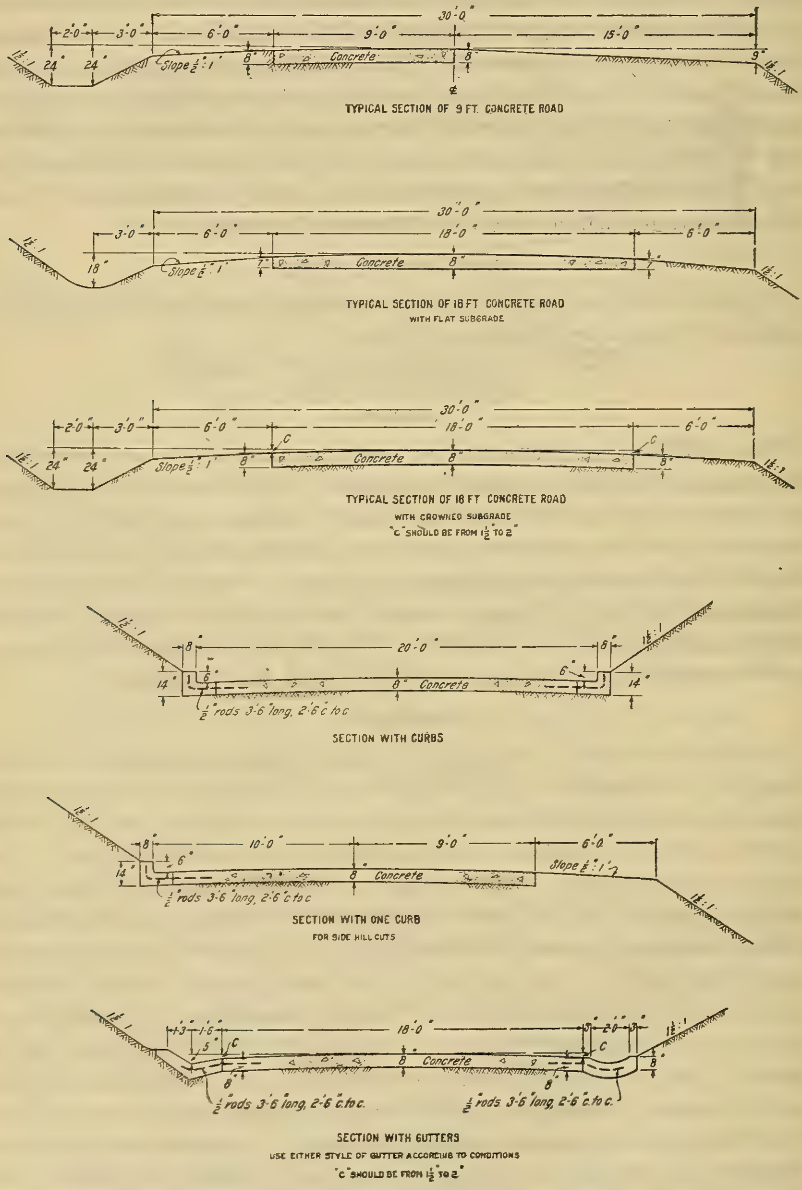


FIG. 7.—Typical pavement cross-sections.

upon the location of the pavement. On sidehill work one line of tile under the edge of the pavement nearest the hill will often suffice, but through cuts it will probably be necessary to use the tile on

both sides. For a more detailed description of the use of tile drains see Bulletin 724, United States Department of Agriculture.

PREPARATION OF THE SUBGRADE.

The essential qualities of the subgrade are uniformity in grade, in cross-section, and in firmness.

The purpose of the rolling to which it is customary to subject the subgrade is to secure uniform firmness. Whether it accomplishes this result is a point upon which opinions differ considerably. Certainly no amount of rolling will result in uniform firmness if trucks or teams are driven over the subgrade to supply the mixer. Under certain conditions it is believed that no rolling is required. In particular it is not believed necessary to roll a newly graded road which has been closed to traffic and which has thoroughly settled before the pavement is placed, providing the concrete materials are hauled to the mixer by means of an industrial railway.

It is difficult to obtain uniform firmness by the use of the customary three-wheel type of macadam roller, because a small strip of the subgrade, wheel-gauge distance from the sides of the road is subjected to twice as much rolling as the edges. The tandem roller is not open to this objection, and it is believed that a condition of uniform firmness can be more nearly secured with a roller of this type than with any other kind.

Any soil with a clay content that is unduly compressed by rolling will swell considerably upon addition of moisture. Unless uniform firmness has been secured by the rolling, the subsequent absorption of moisture will result in uneven swelling which will outweigh any advantage which might have been obtained by rolling. For these reasons it is believed that, in general, light rolling is to be preferred to heavy rolling.

When an old macadam or gravel road is to be surfaced with concrete, the entire surface of the road should be scarified and plowed to the full depth of the existing surface before the subgrade is shaped to receive the concrete. If this is not done it will be almost impossible to secure a uniformly firm subgrade. In case the concrete surfacing is to be wider than the old road surface, the failure to loosen the old surfacing to its full depth will leave a hard, compact core in the subgrade. The uneven support afforded by subgrades with such hard cores is the cause of frequent longitudinal cracks in concrete pavements constructed over old macadam or gravel roads.

The uniform firmness of the subgrade should extend for a distance of at least 1 foot beyond the edges of the pavement, in order to provide a solid support for the side forms.

After the rolling the forms are set true to line and grade and they are then used as a guide for the finishing or trimming operations.

The finishing may be accomplished either by picks and shovels or by the use of a subgrade planer which rides upon the side forms. When materials are delivered to the mixer by hauling over the subgrade it is generally necessary to finish with picks and shovels. If materials are delivered by industrial railway, so that the subgrade is not used for hauling, it will usually be economical to use a subgrade planer. The planer, which is generally drawn by the roller, has its cutting edges so arranged that the slight excess of material trimmed from the subgrade is deposited in windrows at the quarter points, from which it is shoveled to the shoulders. For efficient use of the planer the rough grade should be slightly higher than the finished surface, a condition which is desirable in any case for the reason that it leads to the construction of subgrades of more nearly uniform firmness. Plate I, Figures 1 and 2, illustrate the construction and use of the subgrade planer and the finished subgrade.

The cross section may be either flat or shaped to conform to the finished surface of the pavement. In either case the allowable varia-

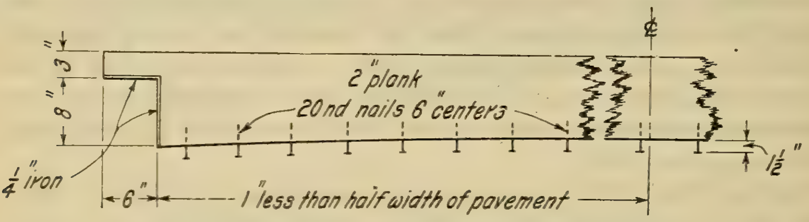


FIG. 8.—Details of nail template used to test the subgrade.

tion from the true grade and cross section is usually limited to one-eighth inch. This small variation is intended primarily to insure that the full thickness of pavement will be secured at all points. The subgrade is tested by means of a nail template (Fig. 8), which is moved back and forth over the forms. Should the test show that any portion is too low, the low area is generally filled with concrete as an integral part of the pavement, though sometimes the contractor is permitted to fill it with hand-tamped earth. While the engineer is charged with securing the full thickness of pavement required by the plans, the contractor aims to furnish that thickness and no more, because any additional concrete represents loss which rapidly runs into a large sum. The natural result is a subgrade as true to grade and cross-section as it is practicable to obtain.

FORMS.

The side forms for concrete pavements may be of steel or wood. Steel forms are preferable and should be used whenever the pavement to be laid exceeds one-half mile in length, and when machine finishing is to be used. A number of makes of steel forms can be pur-

chased. If the pavement is to be machine-finished, heavy forms are desirable and usually are more economical than light ones, as they hold their shape much better under the vibrations set up by the finishing machine. The forms should always be set true to line and grade before the subgrade is finished, in order to serve as a guide for the finishing. It is very essential that the forms be firmly supported and bear uniformly upon the subgrade, as any sag produces an irregular surface in the pavement. The ends of the different sections of forms should be fastened together so that no relative displacement occurs. The joints between the sections on the two sides of the road should not be opposite each other, but should be staggered. The height of the forms should preferably be equal to the thickness of the pavement at the edge. Forms 1 inch less in height than the edge of the pavement can be used satisfactorily, however, by bolting under them a 1-inch strip of wood. These wood strips should be somewhat wider than the base of the forms, so that additional bearing can be secured. In States that use a variable thickness of pavement at the edge this arrangement reduces the amount of forms required for different classes of work.

Forms for concrete pavements should always be oiled before the concrete is placed against them. This oiling prevents the concrete from sticking to them, makes cleaning easy, and prolongs the life of the forms. Any crude oil can be used for this purpose and approximately 1 barrel per mile will be required.

The use of bent forms should be prohibited. It is usually specified that variations in the surface of the pavement of over one-fourth of an inch in 10 feet will not be permitted. These variations in the surface of the pavement are caused to a large extent by the forms, so it would appear that no greater variation should be permitted in the forms than is permitted in the pavement. Forms, therefore, should not be used if their top surfaces vary more than one-fourth inch when tested with a 10-foot straightedge. A sufficient number of forms should be provided so that it will not be necessary to remove them within 12 hours after the concrete is placed.

HANDLING AND HAULING MATERIALS.

For handling and hauling the materials used in concrete pavement construction a number of different methods may be used. The most economical method to employ will, of course, depend upon the particular problems of the work in question. The discussion of this subject will be confined to the general methods which may be employed and the advantages and disadvantages of each.

Nearly all of the materials used in concrete pavements are shipped by rail. The method of unloading the materials from railroad cars will depend to a large extent upon the method of handling the re-

mainder of the work. The following methods may be employed: (1) Unloading by hand into wagons, trucks, or into light movable bodies which are hung against the side of the car and from which the material is dumped into wagons or trucks; (2) mechanical unloaders, using belt conveyors, discharging into wagons or trucks; (3) bucket elevators or skip hoists from pits below the track, discharging into bins; (4) a clam-shell bucket on a stiff-leg, or guy-line derrick; (5) a clam-shell bucket on an auto crane or locomotive crane. (See Fig. 1, Pl. VI.) The first three of these methods can be employed to advantage where a comparatively small amount of material is to be handled and this material can be obtained in bottom dump gondola or hopper cars. They can only be used, however, where the materials, are distributed on the subgrade or placed in stock piles on the shoulders of the road at short intervals. None of them affords any storage capacity at the unloading station.

Pavement construction is seasonal work. The peak demand for materials naturally occurs during the midst of the construction season, and it frequently happens that because of this increased demand regular deliveries and sufficient quantities of materials can not be obtained for the work at hand. With uncertain transportation facilities and a known shortage of railroad equipment for normal business conditions, the storing of materials is practically imperative if work is to proceed without interruption during the construction season. The storing of a considerable quantity of materials can best be done by means of a clam-shell bucket on either a derrick or a crane. On account of its ability to swing through a complete circle, a guy-line derrick can store more material than a stiff-leg. If a stiff-leg derrick is used, the maximum storing capacity will be reached by setting the derrick with one leg parallel to the railroad track. Cranes are considerably more flexible in operation than derricks, and it is possible to store a large amount of material if the storage piles parallel the track. In their principles of operation auto and locomotive cranes are the same, the only difference being that locomotive cranes are considerably heavier, have longer booms, and operate on railroad tracks. If the reloading bin is stationary, the amount of material that can be stored within reach of the bin without rehandling will depend upon the boom length of the derrick or crane. For large storing capacity a boom length of from 50 to 60 feet is desirable. With movable bins, however, good storing capacity without rehandling can be obtained with cranes having a boom length of 30 feet. The use of derricks and cranes combines the labor-saving feature with the storage feature, and where the materials are proportioned or mixed at the unloading yard, their use is practically indispensable.

FIG. 1.—SUBGRADE PLANER IN OPERATION.

FIG. 2.—THE FINISHED SUBGRADE.

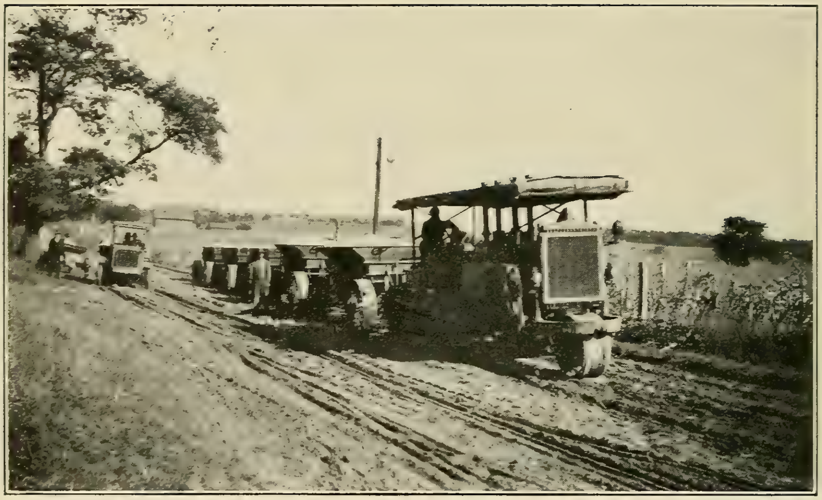


FIG. 1.—HAULING WITH TRACTOR TRAIN.

FIG. 2.—FINE AND COARSE AGGREGATE PILED ON SUBGRADE READY FOR USE.

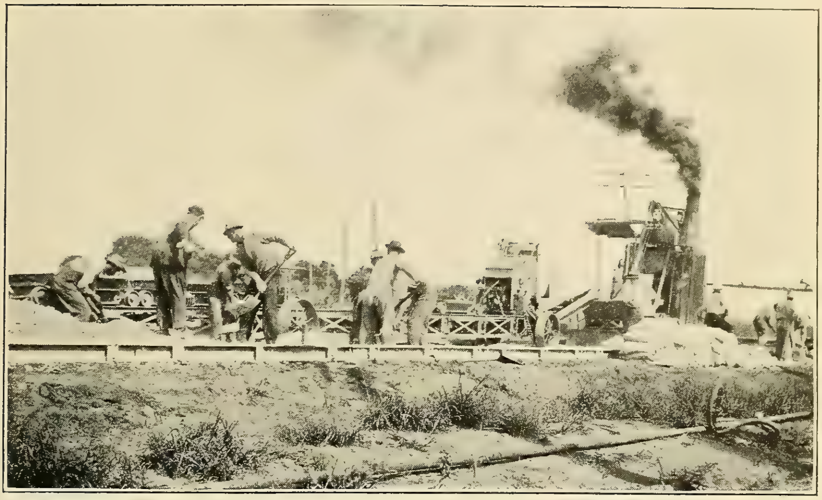


FIG. 1.—CHARGING THE MIXER WITH A BELT CONVEYOR LOADER.

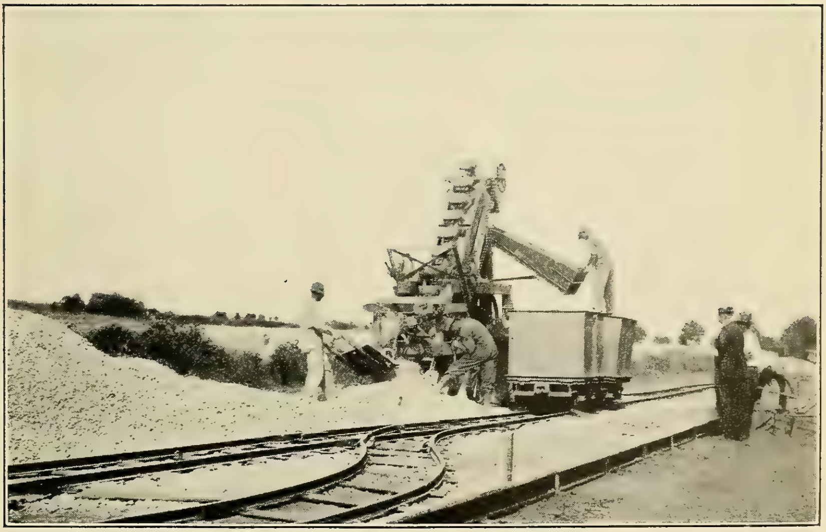


FIG. 2.—LOADING BATCH BOXES FROM SMALL STOCK PILES ON THE SIDE OF THE ROAD WITH A BUCKET ELEVATOR.

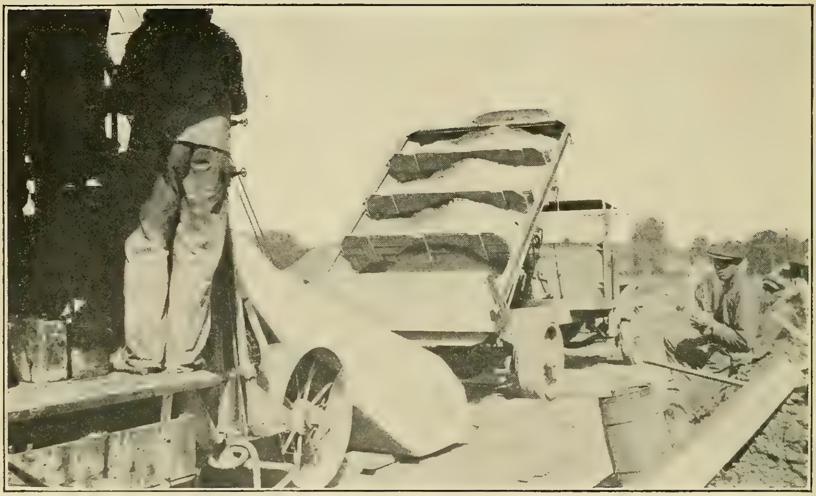


FIG. 1.—CHARGING MIXER WITH PROPORTIONED BATCHES HAULED IN TRUCKS.

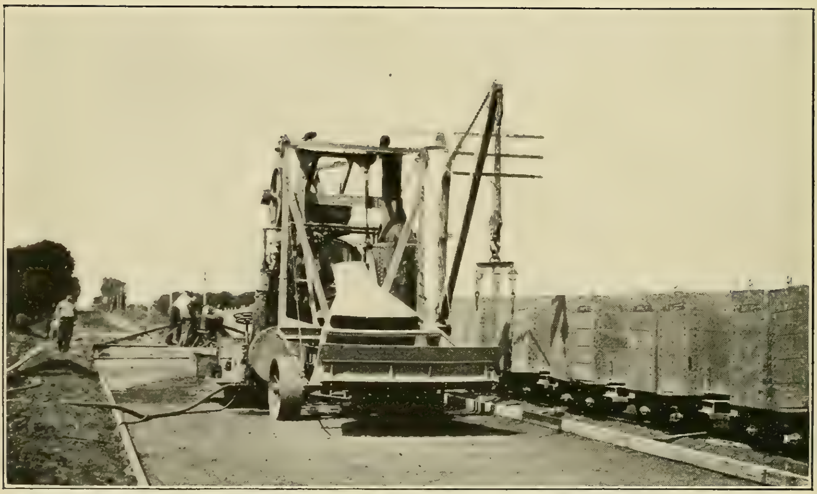


FIG. 2.—INDUSTRIAL RAILWAY HAULING PROPORTIONED BATCHES IN BOTTOM DUMP BOXES.

The equipment used for hauling must fit in with the general method of conducting the work. The proper hauling equipment will depend upon which of the three general methods of operation are employed. By the first method, the materials entering into the construction of the pavement are hauled separately to the work; by the second, they are proportioned at the unloading plant; and when the third method is used, the concrete is mixed at the unloading plant and hauled to the road. If the first method of operation is employed the materials must be distributed on the subgrade (see Fig. 2, Pl. II) or placed in stock piles on the road. Teams, trucks, tractors, or an industrial railway may be used for this hauling. Team haul is generally not economical where the maximum haul exceeds 3 miles. The economy of truck haul depends largely upon the condition of the road hauled over and the care exercised in the operation and maintenance of the trucks. It should not be attempted on a sandy or sandy-loam grade. No class of equipment used in pavement construction depreciates as rapidly as motor trucks if they are improperly operated. Constant changing of drivers and the overloading of the truck are two of the practices which contribute to this rapid depreciation. Trucks for this class of hauling should be equipped with power dump bodies. Tractors are usually used in conjunction with a train of 4 or 5 bottom-dump specially constructed wagons each with a capacity of about 5 cubic yards. The success of the tractor train is due to the large quantity which it is possible to haul at one time. (See Fig. 1, Pl. II.) On account of the great width of pile which the tractor train spreads, the proper distribution of the materials on the subgrade is rather difficult. On roads of average width some shoveling of the materials is necessary before the forms can be set. An industrial railway may be used for delivering the material to the subgrade, but when it is used, it would appear to be doubtful economy to dump the materials on the subgrade and rehandle them into the mixer when they can be handled directly into the mixer from the industrial railway by the use of batch boxes.

When the materials are proportioned at the unloading point, the only practicable method of hauling is with trucks or by industrial railway. Under this method of operation the properly proportioned materials for each mixer batch of concrete are dumped directly into the mixer skip. Each batch, therefore, constitutes a distinct unit and must be handled so that it is kept separate from other batches. Trucks of various sizes may be used for this work. The light trucks are usually equipped to haul only one 4-sack batch. Trucks of larger size, however, may be used by dividing the body of the truck into compartments separated by swinging transverse

doors provided with a locking mechanism so that they can be released separately. (See Fig. 1, Pl. IV.) The number of compartments will depend upon the size of the batch and the capacity of the truck. For truck haul the proper proportions are obtained by the use of measuring hoppers attached to the bins in such a way that the materials will flow into them by gravity and discharge into the trucks by the same process. A measuring hopper should be provided for each kind of aggregate. Where the aggregates are handled from a single divided bin it is possible to arrange the measuring hoppers so that they can both be discharged into the truck at one operation. This arrangement is much preferable to the use of two separate and distinct bins for the aggregates, as the time of loading is practically cut in half. After the truck has received its load of proportioned aggregate it is driven past the cement house, where the proper amount of sacked cement is thrown into each compartment. As the truck is turning around on the road preparatory to backing to the mixer the sacked cement is emptied into the compartments. Where light trucks are used, the sacked cement is sometimes carried on the truck frame, just back of the driver's seat, and unloaded and emptied into the mixer skip by hand as the truck is discharging. The purpose of hauling the cement to the mixer in sacks is to avoid any loss occasioned by high winds. In dumping trucks containing more than one compartment, the dump body is raised and the end gate released, allowing the first batch to run into the loading skip. The truck is then run forward sufficiently to give clearance for the raising of the skip. After the skip is discharged and lowered the truck backs into position for unloading again and the first swinging compartment is released for the discharge of the next batch. With efficient truck operation and a good road to haul over this method of operation may be successfully employed.

The industrial railway is particularly well adapted for hauling proportioned batches. By this method the materials are hauled in removable car bodies or in batch boxes set directly upon the frame or platform of the industrial cars, from which they can be lifted by a suitable hoisting device. (See Fig. 2, Pl. IV.) Greater train capacity is obtained with batch boxes, and they are the more widely used than cars with removable bodies. Three general types of batch boxes are used, distinguished by their method of discharge, as follows: (1) Tip-over boxes; (2) side-discharge boxes; (3) bottom-dump boxes. These boxes are generally rectangular in shape and are constructed either of steel or wood. The wood box has one important advantage over the steel box; it can be easily repaired in case of a train wreck, while steel boxes, once they have become bent, are difficult to straighten. The tip-over box is provided with trun-

nions, placed below the center of gravity of the load, to which the lifting yoke attaches. During the lifting the box is prevented from turning over by a hook attached to the yoke. When the box is in position to dump, the hook is released and the box turns over on the trunnions. If the trunnions are properly located very little "kick back" is noticeable and the load is rapidly discharged. The side-discharge box is provided with a false bottom, which slopes toward the front of the box, where discharge is effected by releasing a hinged door which usually makes up one-half of the front side of the box. The side-discharge box throws the material well to the front of the loading skip, but is somewhat slow of discharge and has a slight tendency to "kick back." The sloping bottom necessitates a larger box and also places the center of gravity of the load higher above the rail than otherwise. The bottom-dump box is discharged by releasing the 2 hinged doors which constitute the bottom of the box. This type of box discharges very rapidly and is practically free from any "kick back." Batch boxes may be loaded by means of measuring hoppers attached to the loading bins, but this arrangement is not necessary, as the box itself serves as a measuring device. The proper height to which the boxes are to be filled with each material may be marked by means of thin nailing strips or bolt heads. The loading plant should be designed so that 4 or more boxes can be loaded at the same time.

Batch boxes are usually loaded from open bins or a loading tunnel. In tunnel loading the industrial train is run under the stored material and loaded from overhead traps. (See Fig. 2, Pl. VI.) The tunnel may be partly or wholly excavated into the ground or it may be constructed of wood on the surface of the ground. The material in either case is stored over the tunnel This method of loading permits practically the entire length of train to be loaded at one time, but it is open to the disadvantage that a considerable amount of material is required in storage which can not be used for loading purposes. The material is simply piled over the tunnel and all of it that lies to the side of the tunnel chutes is practically dead, so far as loading is concerned, unless it be rehandled. Tunnels are rather expensive to construct and this expense does not seem to be justified when the advantages of the tunnel method are compared with those of open bins holding two to three trainloads of material. Open bins with this capacity have successfully loaded trains where the maximum output with one mixer exceeded 1,200 square yards of pavement, 8 inches thick, per 10-hour day, and where the average output was well over 900 square yards per day for weeks at a time. If two mixers are to be operated on a long-and-short haul basis from one central porportioning plant, rapid

loading is essential and a tunnel may be desirable, but for a single-mixer operation open bins are believed to be preferable. Industrial cars may be loaded from open bins either by chutes on the sides of the bins or by running the cars directly under the bins and loading from traps. (See Fig. 1, Pl. VI.) After the aggregates are loaded into the batch boxes the train is run past the cement house, where the required number of sacks of cement are dumped into the boxes. The cement house should be provided with a loading platform at approximately the same elevation as the top of the batch boxes.

A 24-inch gauge is commonly used on industrial railways for pavement construction and the track is generally laid along one shoulder of the road. Passing switches are provided where necessary. Both steam and gasoline locomotives are used to furnish tractive power. The limiting factor in industrial railway hauling is the rate of grade. On sustained grades exceeding 2½ per cent the speed and capacity of trains begins to be measurably reduced. On a 6 per cent grade the capacity is reduced to approximately one-fifth of the amount generally hauled on grades of less than 2½ per cent. The capacity on grades may be increased by the use of geared locomotives, but a locomotive of this type is much slower than a direct-acting locomotive. The great advantage of industrial railway hauling lies in the fact that the subgrade is not cut up by hauling over it, and that hauling is affected comparatively little by weather conditions. The delay on account of bad weather, therefore, is reduced to a minimum. Another important advantage is that the aggregates are kept clean and material is not wasted on the subgrade.

Attempts have been made to haul batch boxes on trucks and on wagon trains, but they have not generally been successful. A derrick independent of the mixer is necessary to discharge the boxes and it has been found that there is not sufficient room on the subgrade to maneuver these large machines or wagons without losing a considerable amount of time.

A combination of batch-box truck haul and industrial railway haul, however, has proved very satisfactory under certain conditions. Where the beginning of the pavement is a mile or more from the unloading plant and the road from the plant to the work contains grades as high as 5 or 6 per cent, an all-industrial-railway haul is not feasible. However, if the road from the plant to the work is in good hauling condition, trucks may be used to haul batch boxes to the beginning of the new pavement, where the boxes may be transferred by means of a portable overhead crane to an industrial railway train for the rest of the trip to the mixer. The transfer of 4 batch boxes from a truck to the industrial cars may be effected in from 5 to 7 minutes. (See Fig. 1, Pl. VII.) The pavement in this case is

begun at the point nearest the unloading plant and as it becomes sufficiently strong to permit traffic the point of batch-box transfer is moved ahead on the new pavement.

The principal advantage of this method of hauling is that it permits the partial use of the industrial railway on work where it could not otherwise be used, thereby securing so far as possible the advantages of industrial railway haul. As the point of transfer is moved ahead an excellent road is made available for a part of the truck haul, and the wear and tear of the trucks is reduced to a minimum. The increased speed of the trucks on the new pavement over the industrial trains compensates for the time lost in effecting the transfer of the boxes from the trucks to the industrial cars. The amount of industrial railway equipment is reduced to a minimum. Usually not more than two locomotives and 1½ miles of track are required for the industrial railway feature of this operation.

If the concrete is mixed at the unloading plant and hauled to the road, trucks are about the only hauling equipment than can be used satisfactorily. Trucks for this purpose should preferably be equipped with turn-over dump bodies rather than hoisting dump bodies. (See Fig. 2, Pl. V.) In hauling, the concrete has a tendency to compact and stick to the truck body, making the discharge rather difficult. If hoisting dump bodies are used, a high angle of hoist is desirable. A comparatively dry concrete is more readily discharged from trucks than a wet, sloppy mix. It is generally accepted that concrete mixed at a central plant should be deposited in the pavement within 30 to 35 minutes after being mixed, though tests made by the Bureau of Public Roads show that the final placement may be delayed by as much as three hours without materially affecting the strength of the concrete. This limitation of time necessarily determines the limit of haul for mixed concrete. Under extremely favorable conditions mixed concrete may be hauled as far as 6 miles. The hauling of mixed concrete is particularly advantageous on work where the supply of water along the road is limited. Its principal disadvantages are that the subgrade must be used for hauling and that considerable delays are caused even by moderate rains.

HANDLING AND STORING MATERIALS.

Cement.—Cement for concrete-pavement construction may be purchased either in bulk or in sacks. Bulk cement is not used to any extent; in fact, its use is practically confined to operations where proportioned aggregate or mixed concrete is hauled to the road. Even for this use it is not recommended on account of the difficulty of measuring the proper quantity of cement for each batch. If it is used, the proper quantity for each batch should be weighed or measured by means of separate compartments placed in the batch

boxes. Bulk cement is usually shipped in open-top cars, covered with tarpaulins for protection from the weather. It may be unloaded with a clamshell bucket. Storage for cement should always be provided at the unloading yard. The storage house should be leak-proof and should be lined with roofing paper to prevent the free circulation of air. The floor of the house should be elevated above the ground. The necessary storage capacity will depend upon the size of the job and the capacity of the equipment, but for the average small job of approximately 4 miles, storage capacity should be provided for about 2,000 barrels of cement. Storage capacity is especially desirable in case it should be necessary to hold the cement until tests can be obtained or until the cement has aged sufficiently to pass the soundness test. Where the materials are hauled to the road separately, the cement may be hauled by any of the methods previously described for hauling aggregates separately. With this method of operation, some storage of cement on the road is desirable. Cement stored on the road should be piled on boards, or racks, at convenient intervals and shelter should be provided for use in case of rain.

Aggregate.—A number of methods may be employed for handling the materials into the mixer. Where the aggregates are distributed on the subgrade they may be handled into the mixer skip by wheelbarrows or by a belt-conveyor loader as shown in Figure 1, Plate III. Wheelbarrows are most commonly used, and, where labor is plentiful and inexpensive, this method will prove economical. The materials should be distributed in such manner that no unnecessary labor and time will be consumed in wheeling the materials long distances to the mixer. The belt-conveyor loader consists essentially of a long, steel frame, on traction wheels, operated by independent power, on which low, bottom-dump measuring boxes are placed for measuring the materials and discharging them upon the belt conveyor. A wide continuous belt carries the materials forward to the loading skip. The principal advantage of the conveyor loader is that it does away with the wheelers. Its disadvantages are that the aggregates must be very accurately distributed on the subgrade for efficient operation, and on roads of average width it is very difficult to distribute the materials within the area of the subgrade so that no shoveling of material is necessary in setting the forms.

If the aggregates are stored in small stock piles on the subgrade or on the shoulders of the road, they are usually picked up by some form of bucket elevator and loaded in the proper proportions into batch boxes, light trucks, or carts in which they are hauled to the mixer and discharged directly into the skip. If batch boxes are used, they are hauled to the mixer by horse-drawn cars running on

short sections of industrial track. (See Fig. 2, Pl. III.) The principal advantage of this system is that the materials can be placed on the shoulders of the road before the grading is begun, thereby allowing the teams or trucks to use the road before it is disturbed. Where materials are delivered to the mixer in batch boxes a derrick is necessary to hoist the boxes from the cars and swing them over the mixer skip. For this purpose the derrick may either be attached to the mixer or independent of it. A derrick attached to the mixer may be operated either by utilizing the power developed by lowering the skip or by independent power obtained from the mixer. That which utilizes the power developed by lowering the skip requires fewer working parts and less power expenditure than any other method. It is not as flexible, however, as a derrick operated by independent power and has the disadvantage that the same relative elevation must be maintained between the track and the subgrade in order that a constant height of lift may be secured to swing the boxes free of the cars. There is no particular advantage in using a derrick independent of the mixer when batch boxes are discharged into the mixer skip. The added expense of operation does not appear to be justified. However, for very large mixers, with overhead charge, a crane independent of the mixer must be used. These mixers are usually not equipped with traction and therefore depend upon an autocrane for movement.

Water.—The usual sources of water supply are city mains, running streams, lakes, ponds, or wells. A city main is the most satisfactory source of supply that can be obtained, as a uniform pressure is secured and no pump is required. It is seldom, however, that the work is located so that city water can be used. A frequent error on the part of engineers and contractors is that of overestimating the amount of water which can be obtained from any given stream or pond. Information should be obtained locally as to dry-season flow before placing dependence on small streams for water supply.

The most practicable method of delivering water is to pump it through a pipe line laid along the road. The diameter of the pipe line should be not less than 2 inches. If very large mixers are used, a pipe of larger diameter will be necessary in order to obtain sufficient water for curing. Tees for supplying water to the mixer and for sprinkling should be placed in the pipe line at intervals of from 200 to 300 feet. Gate valves should be spaced about 1,000 feet apart and unions about 500 feet apart. Rubber hose of 1½ inch diameter should be used for connecting the pipe line with the mixer, while 1-inch hose is usually used for sprinkling. Provision should be made for the expansion of the pipe either

by providing expansion devices on the pipe line or by "snaking" the line. For cold-weather construction drain valves should be placed at all low points in order that the pipe may be drained to avoid damage by freezing.

Either steam or gasoline pumps may be used for supplying water. The horsepower required to deliver a stated quantity of water at any given point will depend upon the length and size of the pipe line and the height the water has to be raised from the source to the work. A method of computing the horsepower required for the delivery of different quantities of water is given in the appendix, page 63. To avoid overloading the pump, a relief valve should be placed in the pipe line near the pump. This valve should be set to open when the pump pressure exceeds that needed, and provision should be made to discharge the water back into the source of supply so that waste of water will be avoided.

The amount of water required for concrete-pavement construction is approximately 30 gallons per square yard of pavement. A 4-sack mixer laying an average of 800 square yards of pavement per 10-hour day will require 24,000 gallons of water, or 40 gallons per minute, for mixing and curing. The failure of the water supply is responsible for many of the delays in concrete construction. These delays may be overcome to a marked extent by using double-unit pumps. The added expense of this type of pumping plant is usually justified on work of any considerable magnitude.

MIXING AND PLACING.

The quantities of all materials entering into the concrete should be accurately measured before they are placed in the mixer. If wheelbarrows are used, their capacity should be checked by means of a 1-cubic-foot measuring box. No size of batch should be permitted which would require fractional sacks of cement. Concrete for pavements should invariably be mixed by means of mechanical mixers. If it is mixed at a central plant and hauled to the road, any satisfactory type of building mixer may be used. If it is mixed on the road, a paving mixer provided with traction and equipped with a device for distributing the concrete will be the most economical to use. Figure 1, Plate V, shows one type of mixer and a finishing machine.

The device to convey the concrete from the drum of the mixer to its place in the road may consist of a bucket and boom attachment or a chute. The bucket and boom device is believed to be preferable for pavement work, especially if a relatively dry mix is required. In chute distribution the tendency is to mix the concrete rather wet so that it will readily flow down the chute, and this is objectionable

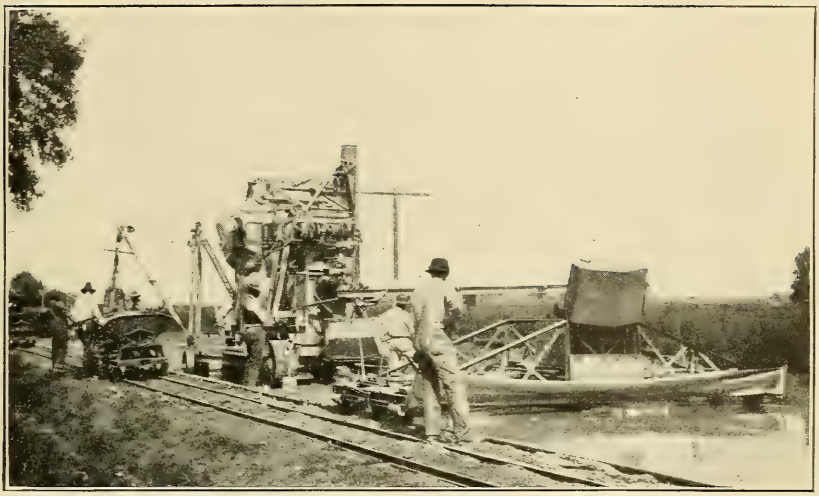


FIG. 1.—MIXING AND FINISHING THE CONCRETE.

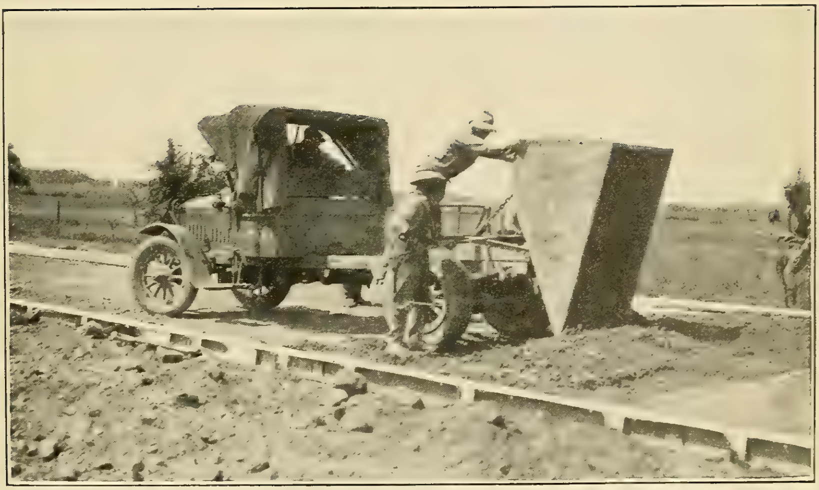


FIG. 2.—DUMPING MIXED CONCRETE ON THE ROAD.

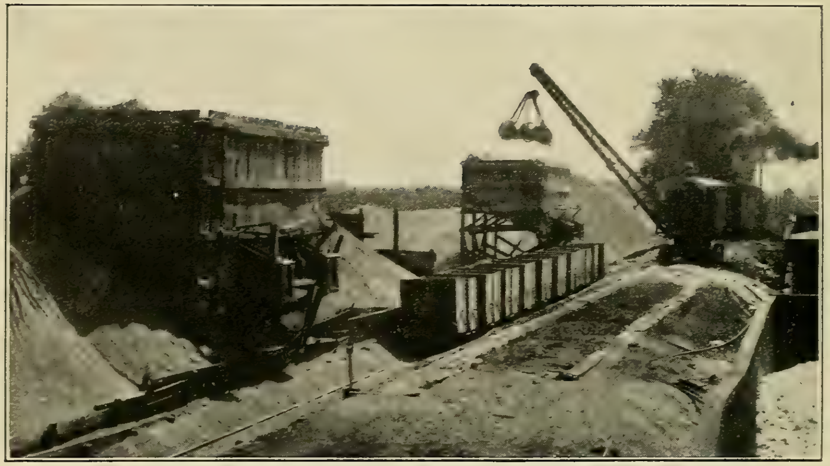


FIG. 1.—LOADING BATCH BOXES FROM OPEN BINS.

FIG. 2.—LOADING TUNNEL FOR BATCH BOXES.

because the excess of water reduces the strength of the concrete, and there is a tendency for the mortar to separate from the coarse aggregate.

The concrete should be mixed thoroughly to a uniform consistency. The time of mixing bears an important relation to the quality of the output. Generally speaking, the longer the time of mixing within practical limits, the greater will be the strength and the resistance to wear. On the other hand, longer-mixing means reduced production and more expensive concrete. The time of mixing should be long enough to secure the maximum of strength at a minimum of cost. One minute of mixing appears to meet this condition. Certainly, the time allowed should not be less, and it is questionable whether the increased strength obtained with a longer mix justifies the increased expense. To insure the mixing of every batch for the proper length of time the mixer should be equipped with an automatic timing device, or a combination timing and locking device that will prevent its discharge until all the materials have been mixed together for the minimum time required.

The consistency of the concrete also affects its strength and wearing qualities. For maximum strength and wear, only sufficient water should be used in mixing to secure a good workable consistency. The water-measuring tank on the mixer should be used as a means of obtaining the proper amount of water for each batch. A test known as the slump test is employed as a check on the consistency. The slump test is made by filling a metal form with the concrete to be tested, tamping it down until all the voids are filled and a slight film of mortar appears on the surface. The form is then removed and the vertical settlement or slump is noted as a measure of its consistency. The form may be either a cylinder or a frustum of a cone. If a cylinder is used, it is 6 inches in diameter and 12 inches in height. The settlement or slump in this case should not exceed 2 inches for proper consistency. If the frustum of a cone is used, the top diameter should be 4 inches, the base diameter 8 inches and the height 12 inches. The slump in this case should be not greater than 1 inch, nor less than ½ inch for proper consistency. (See Fig. 1, Pl. IX.)

After the concrete has been mixed the required length of time it should be placed between the side forms to the full thickness of the pavement and in successive batches for the entire width. If the subgrade is dusty, it should be sprinkled lightly before the concrete is placed. Each batch of concrete should be dumped as nearly in place as practicable and leveled off with shovels. If for any cause a wet batch or a batch in which portions of the aggregate are separated is deposited in the road, it should be thinly distributed over the sub-

grade so that there will be no segregated material in the surface of the pavement. Exceptionally wet batches should be shoveled from the subgrade and wasted on the shoulders.

FINISHING THE SURFACE.

After the concrete has been spread approximately to the required cross-section, the finishing operations are begun. These operations consist of striking-off and tamping the concrete, and finishing the surface. Two methods may be employed, viz, hand finishing and machine finishing. In hand finishing, each operation must be performed separately, while in machine finishing all operations can be performed simultaneously. Machine finishing is greatly to be preferred.

Hand finishing.—The concrete is first struck off with a strike board having from one-fourth to one-half inch more crown than the finished crown of the pavement. This allows for a slight amount of settlement when the concrete is compacted. The striking off is accomplished by advancing the strike board with a combined longitudinal and crosswise motion. A slight surplus of concrete should always be maintained ahead of the strike board. The tamping should be done by means of short, quick, up-and-down strokes of the tamper, which should have the same crown as the finished road. The best results are obtained by pivoting one end of the tamper on the side forms and advancing the other from 2 to 3 feet, at the same time tamping the area over which the tamper is advanced. This operation is then repeated by pivoting the tamper on the opposite form and advancing the end which was first pivoted. As soon as possible after the concrete has been tamped it should be rolled with a roller having a smooth, even surface and weighing approximately three-fourths of a pound per inch of length. The roller should preferably be 10 inches in diameter, and 6 feet in length and a long handle or ropes may be provided with which to operate it from the sides of the pavement. The purpose of rolling is to eliminate slight inequalities in the surface and remove the surplus water. After the pavement has been rolled the final finish is obtained by means of a belt. A 10 or 12 inch canvass or rubber belt is generally used for this purpose. The belt should be at least 2 feet longer than the width of the pavement and should be provided with wooden handles at each end. The first application of the belt should consist of long strokes with only a slight longitudinal advance at each stroke. A greater longitudinal advance and somewhat shorter stroke should be used for the second belting. The final belting should not be done until after the water glaze or sheen on the surface disappears. It should consist of a rapid longitudinal advance with as short a stroke

as possible. After the final belting the pavement should present a smooth, uniform surface. Suitable designs for the tools used in the hand finishing of pavements are shown in Figures 9 and 10. The small, long-handle float can be used to great advantage in touching

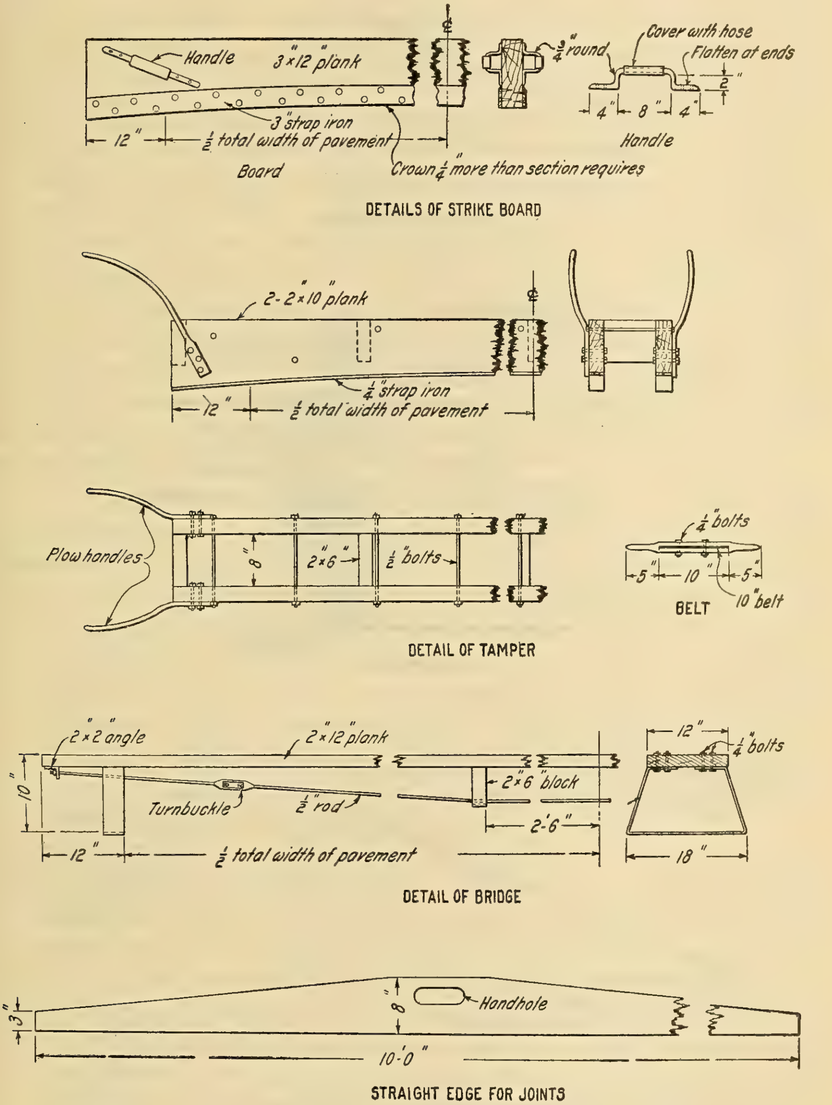


FIG. 9.—Details of tools used in hand finishing.

up rough spots in the pavement when a particle of coarse aggregate has been dislodged by the belt.

Machine finishing.—Machine finishing is accomplished by means of a power-driven mechanical finishing machine. (See Fig. 2, Pl.

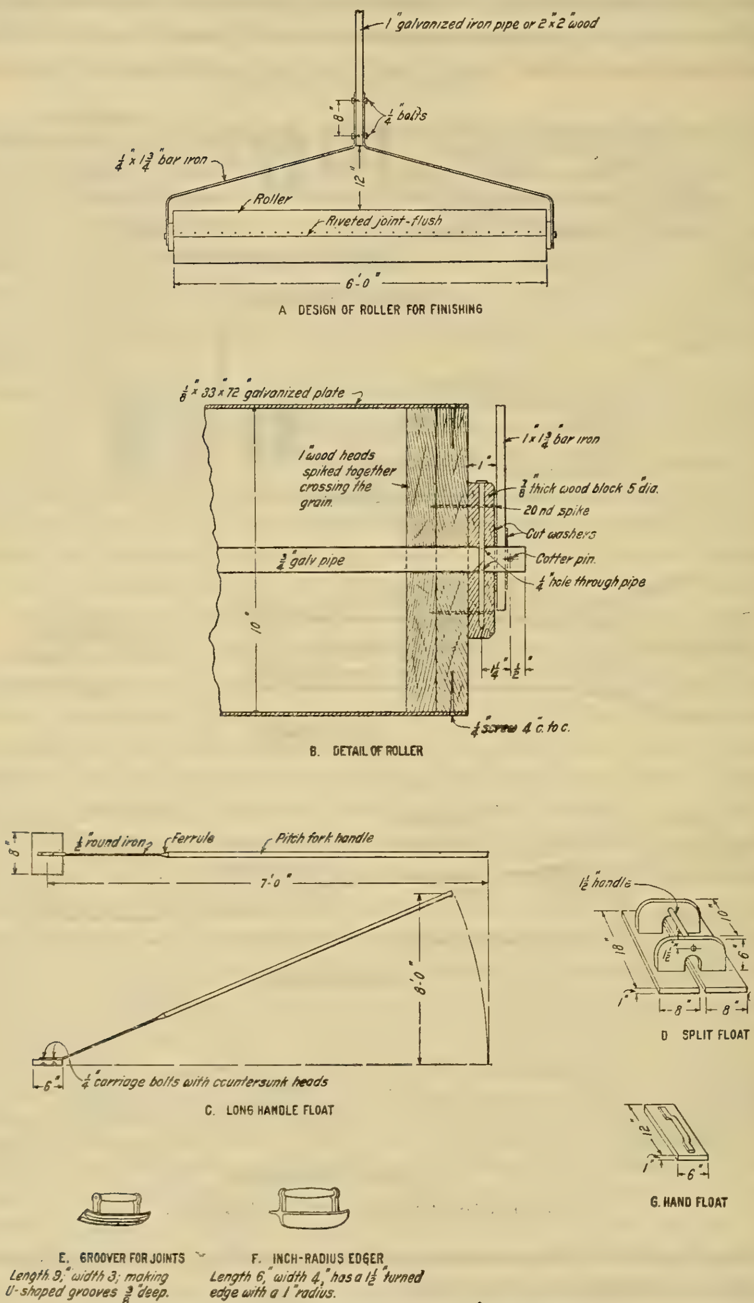


Fig. 10.—Details of tools used in hand finishing.

VII.) The machine is supplied with flanged wheels, which travel on the side forms used for the pavement. Power for traction and operation is generally furnished by an air-cooled gasoline engine. The machine is provided with a striking template, a tamper, and a finishing belt so arranged that each may be operated separately, or any two, or all operated simultaneously. In practice, the striking template and tamper, and the tamper and belt are usually operated at the same time. After the concrete has been roughly spread it is struck off by means of the striking template. On the second passage of the machine, the strike board is still in place and the tamper is placed in operation. The third time over usually only the tamper is permitted to operate. For the fourth passage both the tamper and the belt are used. For the final finishing operation either the belt alone is employed, or the tamper and belt. A common fault where machine finishing is used is the tendency to let the machine do a large part of the spreading. The machine was never intended for this purpose and will not operate satisfactorily if a large amount of concrete must be pushed ahead of the striking template. For best results not more than 2 inches of excess thickness should be ahead of the striking template at any one time.

The principal advantages of a finishing machine from the standpoint of cost are derived from the striking template and the tamper. These devices replace the usual heavy timber strike board and tamper, which require from two to four men to operate them. From an engineering standpoint the machine serves a useful purpose by making it possible to use a drier and hence a stronger concrete than it would be possible to use if hand finishing methods were employed. Its principal disadvantage is that it is not adjustable to various widths of pavement without providing new trusses, striking template, and tamper. The objection is not serious, however, in States that have their road widths well standardized.

From the standpoint of the traveling public the finish of the surface is the most important quality of the pavement. Regardless of its strength and wear, the traveler invariably judges a pavement by its riding qualities. A smooth surface should, therefore, be the constant aim. The surface should be frequently tested by means of a straightedge laid parallel to the center line of the pavement. Variations in the surface of over one-fourth inch in 10 feet should be corrected before the final belting. The joints are the chief source of trouble in securing a good surface. High joints can practically be eliminated by the use of the straight-edge, and its use is particularly recommended at joints between sections of concrete laid on different days. The edges of the pavement and of all joints should be rounded to about 1-inch radius with an edging tool.

PROTECTING AND CURING THE CONCRETE.

The quality of the concrete depends to a great extent upon the conditions under which it is cured. A concrete cured with the proper amount of moisture has strength and wearing qualities almost twice as great as the same concrete cured in the open air. Either of the following general methods may be used for curing: Covering the pavement with earth or straw, and keeping this material moist; or covering the pavement with water. Until the pavement has set sufficiently hard so that it will not be damaged by walking upon it, it should be protected with a canvas covering. The canvas covering may be supported by wooden frames or laid directly on the concrete if care is taken to avoid marring the surface. (See Fig. 1, Pl. VIII.) Under ordinary weather conditions about 24 hours will be required for the concrete to set sufficiently hard not to be damaged by walking upon it.

If an earth covering is used it should be at least 2 inches thick and should cover the edges of the pavement. It should be thoroughly watered twice each day for a period of 14 days and remain upon the road for at least 20 days from the time of its application. The earth for covering is usually obtained from the shoulders or the sides of the road. Where earth for covering is difficult to obtain, as for example, where the shoulders are composed of hard compacted material, straw may be used, in which case the covering should be not less than 4 inches thick after wetting. The principal advantage in the use of straw is that it can be easily loaded and hauled forward for use again. In localities where straw can be obtained at small cost it is believed to be more economical than earth.

The method of curing by covering the pavement with water is commonly called "ponding." (See Fig. 2, Pl. VIII.) The water is retained on the pavement by earth dams placed across and along the edges of the pavement. The pavement is then covered with water to a depth of 2 inches. The water should be maintained on the surface for a period of not less than 14 days. Flooding is generally done in the evening when the water is not needed for the mixer. The ponding method is more positive than any other, and should be used wherever possible. It can not be used satisfactorily, however, on grades in excess of 3 per cent or where the earth available for the dams will not retain the water.

During the period of curing the roadway should be kept entirely closed to traffic. If the weather conditions are favorable for rapid curing, as for example during midsummer, the pavement should be sufficiently strong to be opened to traffic at the end of 21 days. In cold weather a longer time should elapse before traffic is permitted on the pavement.

When the average temperature is below 50° F. it is better to omit covering and ponding, and sprinkle the pavement only when the concrete shows signs of drying out too rapidly. Sprinkling night and morning will usually be sufficient; it should be omitted altogether when there is danger of freezing.

PLACING CONCRETE IN FREEZING WEATHER.

Concrete pavement construction should not be attempted during freezing weather. Satisfactory results can not be obtained, and the expense of attempting to heat the water, the aggregates, and the finished work is not justified unless only a very short length of pavement is necessary in order to complete an important piece of work. If danger of freezing develops after the concrete is laid and before it has developed a hard set, the pavement should be protected by means of a heavy layer of straw, covered with canvas. Concrete should not be placed upon a frozen subgrade, and should not be mixed and placed when the air temperature is below 35° F.

ORGANIZATION AND EQUIPMENT.

When it is considered that from 50 to 60 per cent of the total cost of constructing a concrete pavement is chargeable to the equipment and labor employed in doing the work after the materials are delivered at the unloading plant, the importance of proper organization, proper equipment, and economical methods becomes clearly apparent. Failure to give these features proper consideration may easily result in adding from 10 to 25 per cent to the cost of a concrete pavement, and has no doubt frequently caused contractors to sustain a net loss on projects where profits might have been made.

It is not the province of this bulletin to furnish detailed rules for the guidance of contractors in planning and executing their work, but it seems desirable to discuss briefly a few important points which contractors and engineers in charge of force account work should consider in concrete pavement construction. The points which are of most importance and to which the discussion will be confined are concerned first with the proper order and progress of the work; second, the selection of equipment; and, third, the amount of capital necessary to carry on the work economically.

ORDER AND PROGRESS OF THE WORK.

In constructing a concrete pavement it is especially desirable that the work of mixing and placing the concrete shall proceed without unnecessary interruption after it is begun. When the mixer is permitted to stand idle for even a few days, the force of laborers employed in operating it will usually become more or less disorganized and a certain amount of loss and unsatisfactory work will generally

result when the mixing is resumed. On this account the order and progress of the work should ordinarily be planned with the primary view to keeping the mixer going full time every working day that the weather will permit. This means that ample provision should be made for completing the drainage structures, the grading, and the preparation of the subgrade well ahead of the mixer. Provision should also be made for supplying the mixer with all necessary materials. Where the materials are obtained by rail shipment, and it is expected that these shipments will be rather irregular, sufficient material for at least ½ to 1 mile of road should be stored on the subgrade or at the unloading yard before the mixing is started. This material can be stored with a comparatively small working force, so that an interruption of their work will not be as costly as a delay to the full hauling and mixing force.

The small drainage structures should preferably be completed in advance of the grading in order to obviate the necessity of moving embankment material the second time. They should always be completed in advance of the pavement. It is not economical to leave out a section of the pavement over a small culvert, and this practice should not be permitted. The extra expense involved in going back and putting in a section of this kind after the pavement has progressed a considerable distance ahead is usually considerable and is often underestimated. This method of doing the work also involves a delay in opening the road, adds two extra joints, and usually results in securing an improperly cured pavement over the culvert.

Organizing a force of laborers to operate a paving mixer efficiently requires considerable skill in handling men. The best results are generally obtained when a mixer is fully manned and each laborer is assigned a definite work to perform.

Diagrams showing organization and plant layout for a number of typical methods employed in concrete pavement construction are given in Figures 11 to 15, inclusive. These organizations and layouts have been used in actual construction work and have proved to be very satisfactory.

EQUIPMENT.

Any discussion of equipment must necessarily be more or less general, because the same equipment is not always best suited for each particular piece of work. Each project possesses certain characteristics which determine the kind of equipment best adapted for handling it. A contractor may either wait until he has secured a contract before he decides on the type of equipment to purchase or he may purchase the equipment which he feels will give him the best satisfaction and only bid on work for which this equipment is suited.

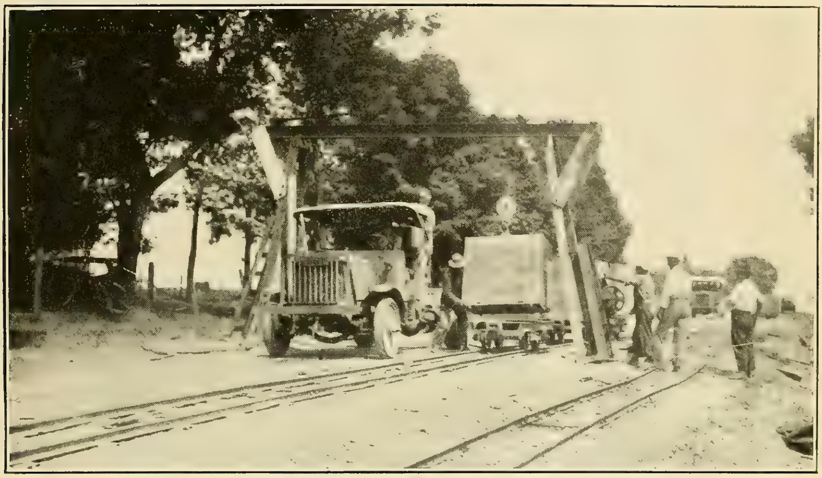


FIG. 1.—TRANSFERRING BATCH BOXES FROM TRUCK TO INDUSTRIAL RAILWAY.

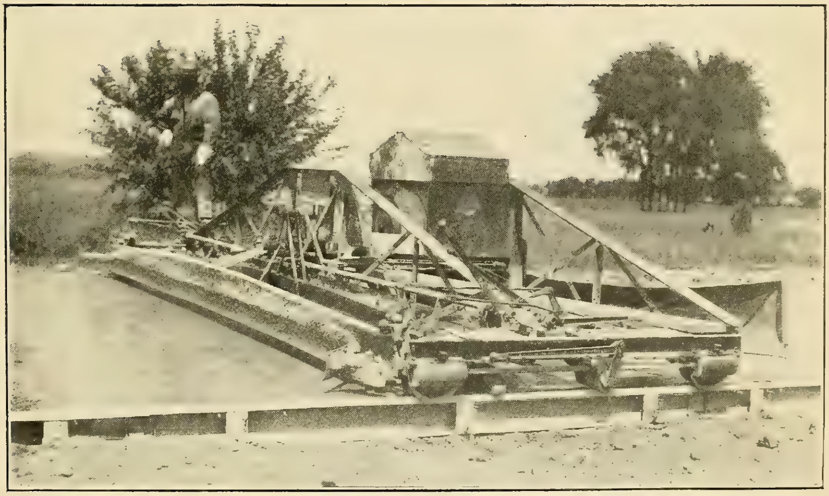


FIG. 2.—MECHANICAL FINISHING MACHINE FOR CONCRETE PAVEMENTS.

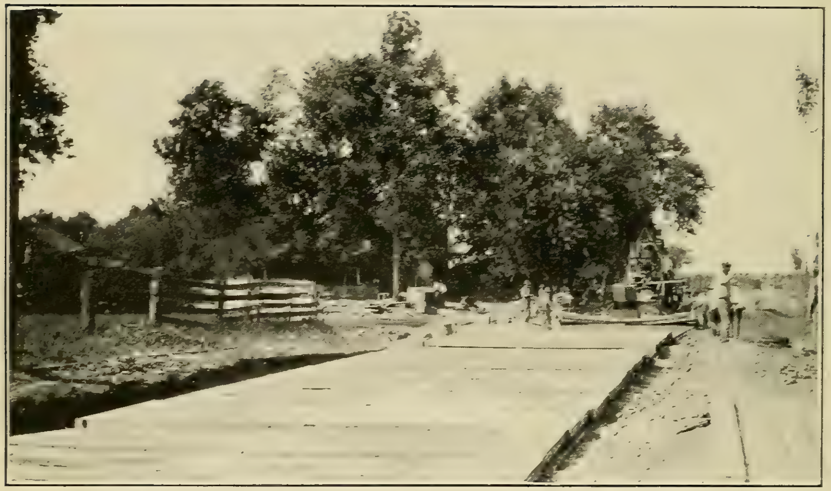
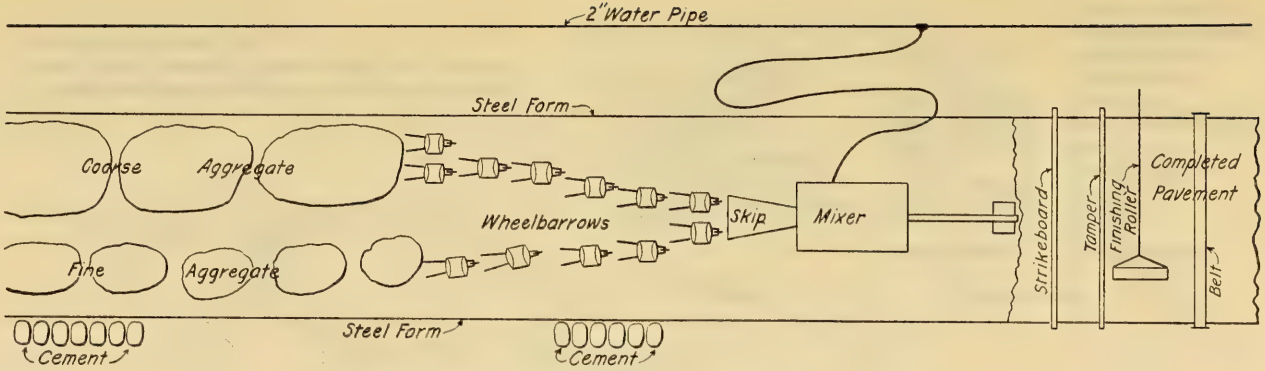


FIG. 1.—PROTECTING NEWLY LAID CONCRETE WITH CANVAS STRETCHED ON WOODEN FRAMES.

FIG. 2.—THE PONDING METHOD OF CURING.



ORGANIZATION AND EQUIPMENT

DISTRIBUTION OF FORCE

1 Foreman
7 Men wheeling coarse aggregate
3 Men loading coarse aggregate
4 Men wheeling fine aggregate
2 Men loading fine aggregate
2 Men handling cement
1 Mixer Engineer
1 Fireman
1 Formsetter
3 Men spreading concrete
2 Men striking off
2 Men tamping
1 Concrete finisher

NOTE

Men for preparing the subgrade, setting the forms, and covering the concrete with earth should be provided in addition to the above.

This organization is capable of laying from 350 to 400 linear feet of pavement 8 inches thick 16 feet wide per 10 hour day under favorable conditions.

MAJOR EQUIPMENT

1 Four-sack Concrete mixer
1 Road Roller
12 Wheel barrows
1 Strike board
1 Tamper
1 Concrete finishing roller
1 Finishing belt
Pump and water pipe
Steel forms
Shovels-Forks and miscellaneous

FIG. 11.—Typical organization and plant layout, wheelbarrow equipment.

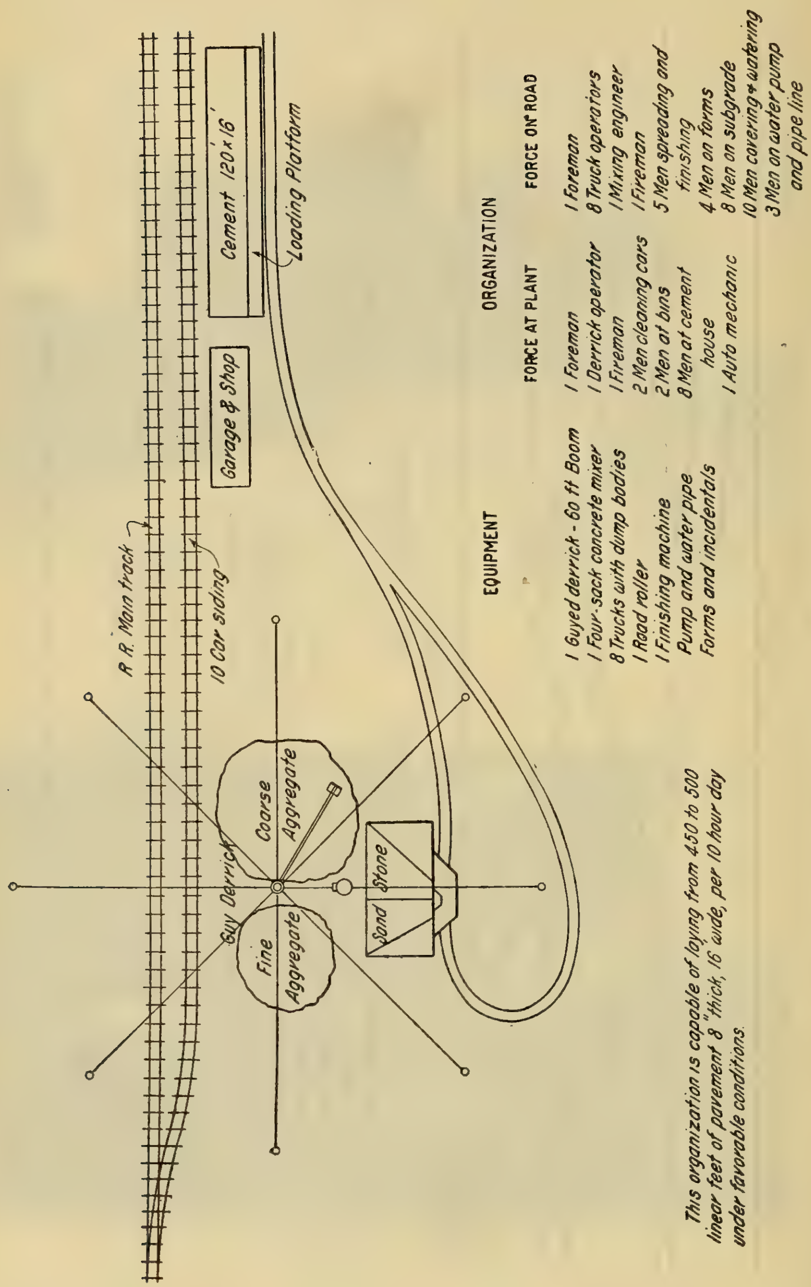


FIG. 12.—Typical organization and plant layout, truck haul.

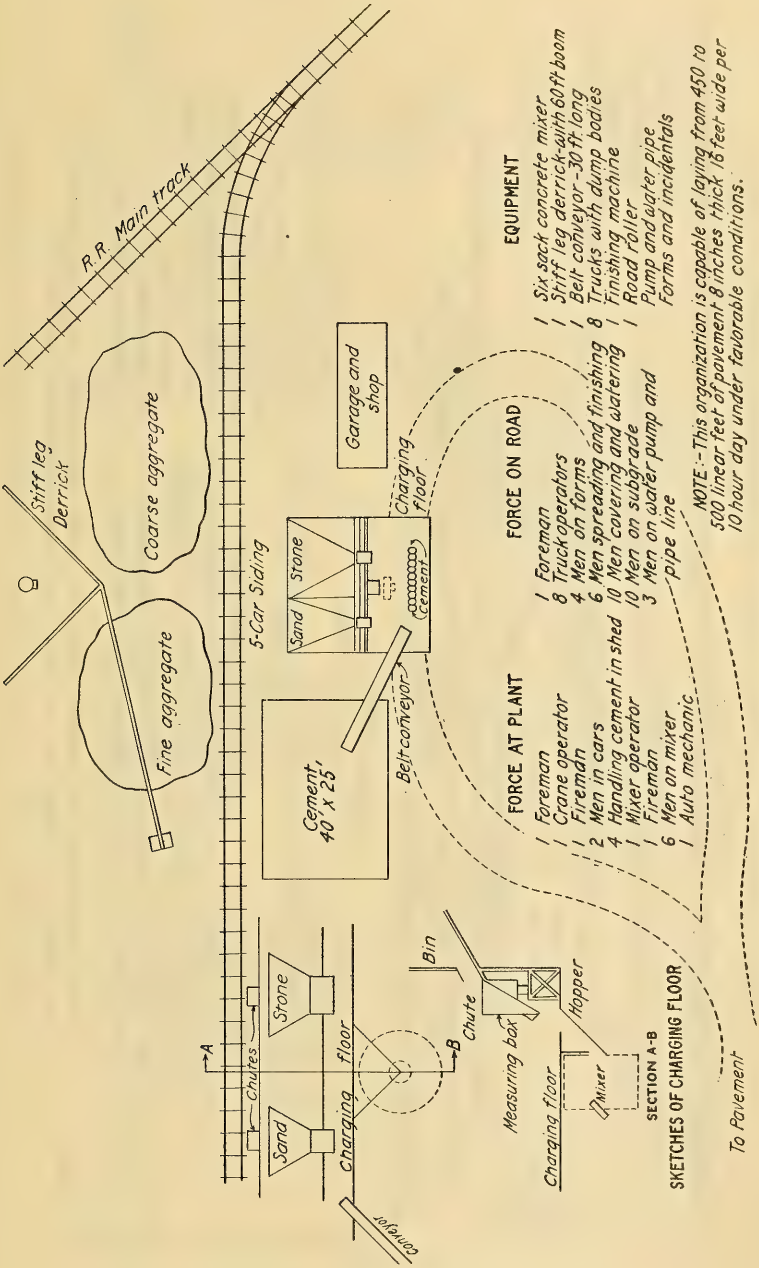


FIG. 13.—Typical organization and plant layout, central mixing, truck haul.

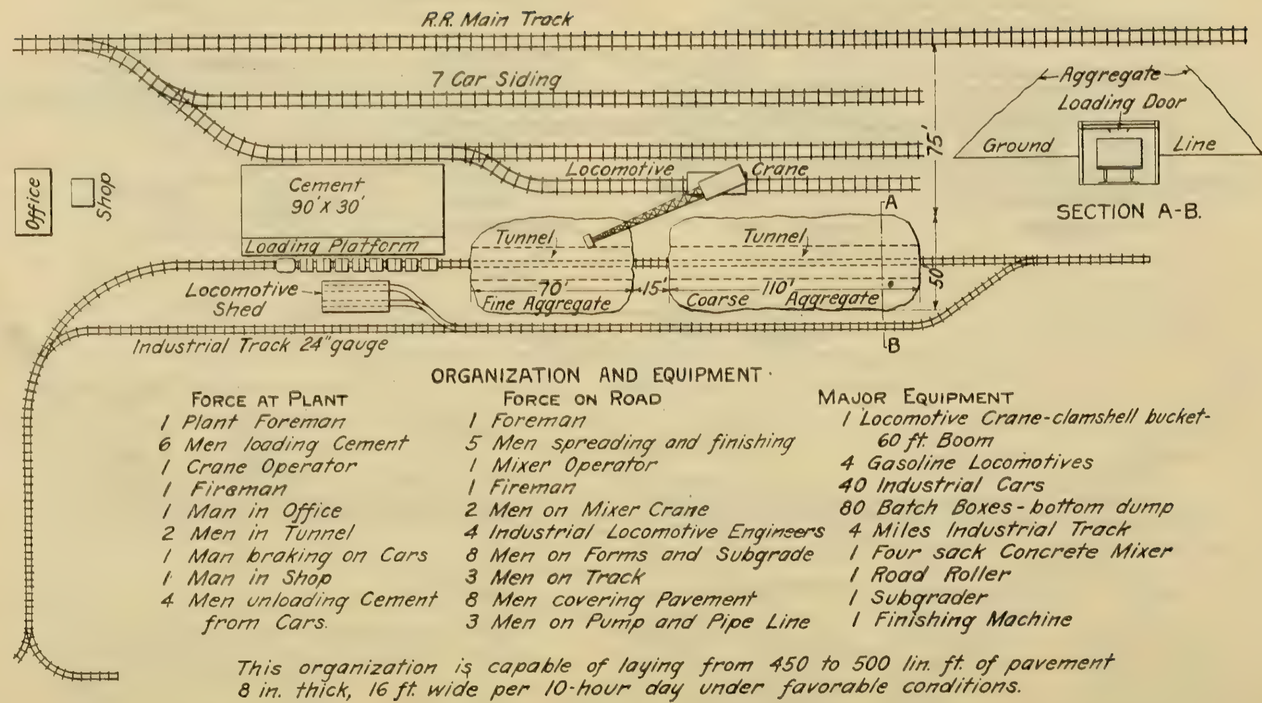


FIG. 14.—Typical organization and plant layout, central proportioning, tunnel loading, industrial haul.

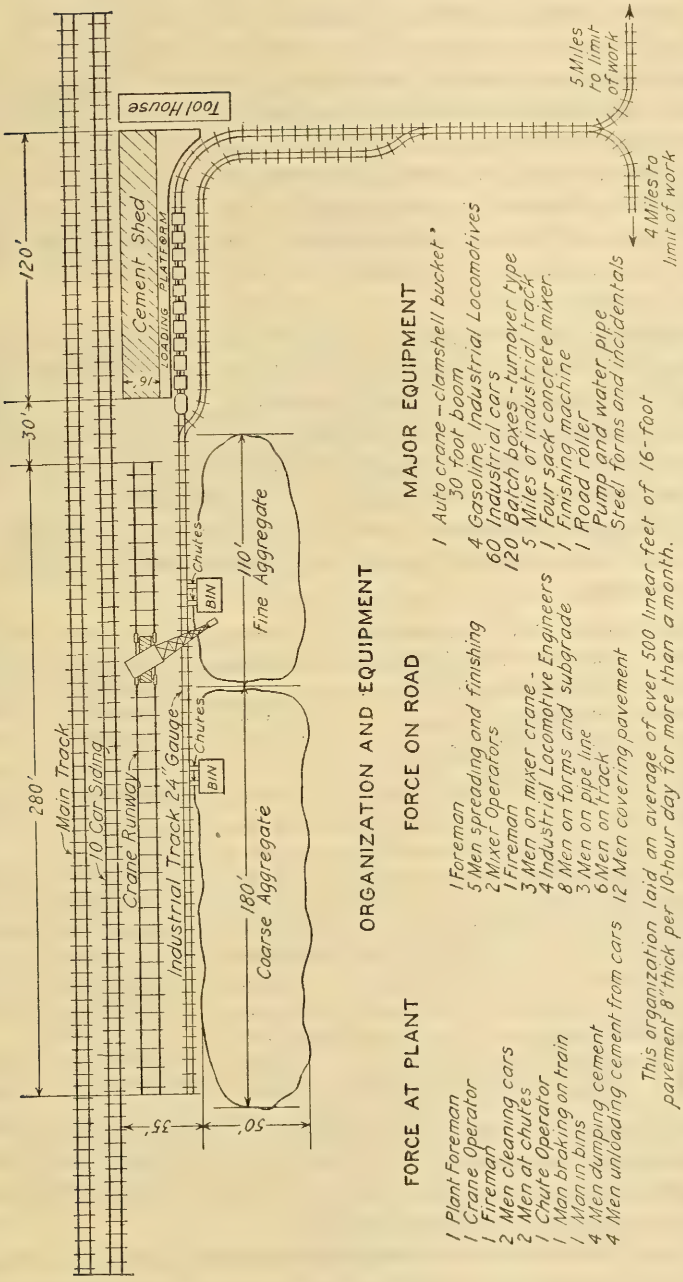


FIG. 15.—Typical organization and plant layout, central proportioning, open bin loading, industrial haul.

The magnitude of the work should be a guide in purchasing equipment. One 2-sack mixer would be as much out of place on a 10-mile contract as an 8-sack mixer would be on a 1-mile contract. Considering the two extremes of too little equipment and too much equipment, the tendency of contractors, especially those just entering this class of work, is toward too much equipment. The success of a contractor upon the completion of any work should be measured by the amount of money the work has produced, not by the amount of equipment he has on hand. The aim of the contractor, therefore, should be to finish the work in the specified time and use the smallest amount of equipment with which operations can be carried on economically.

The capacity of each piece of equipment purchased should bear its proper relation to the capacity of the combined equipment in order that all parts may be nicely balanced. A large mixer with a small unloading plant or poor transportation facilities would be a poorly balanced equipment on which the contractor would not receive proper returns in efficiency for his expenditure.

The following list, based upon 1920 prices, will give some idea of the cost of the various kinds of equipment used in building concrete pavements:

Locomotive cranes with clamshells ....each..	$15,000.00 to	$20,000.00
Automotive cranes with clamshells ....do...	6,500.00 to	12,000.00
Derrick cranes with clamshells ....do...	4,500.00 to	6,500.00
Mixers—4-sack capacity ....do...	6,500.00 to	9,000.00
Road rollers—macadam type ....do...	3,500.00 to	4,800.00
Industrial locomotives:		
Gasoline ....do...	2,500.00 to	4,500.00
Steam ....do...	5,000.00 to	8,000.00
Industrial railway cars ....do...	75.00 to	90.00
Industrial railway track, 24-inch gauge...per mile..	4,500.00 to	5,800.00
Industrial batch boxes ....each..	35.00 to	70.00
Concrete finishing machines ....do...	1,600.00 to	2,000.00
Steel forms ....per lineal foot..	.50 to	.60
Subgrade planer ....each..	400.00 to	500.00
Water pump ....do...	600.00 to	1,000.00
2-inch wrought-iron pipe ....per lineal foot..	.22 to	.25
Tractors, caterpillar, 5-ton ....each..	5,500.00 to	6,500.00
Trucks, 3-ton capacity, with dump bodies ....do...	3,000.00 to	5,000.00

The equipment necessary for doing the rough grading and building culverts in connection with concrete pavement work is not essentially different from that required for other types of pavements and needs no particular discussion here.

The total expenditure for equipment for preparing the subgrade mixing and placing and finishing the concrete depends on the rate at which it is proposed to carry on the work. Based on 1920 prices for equipment, a wheelbarrow outfit, consisting of a four-sack mixer,

finishing machine, road roller, water pump, pipe, forms, and all other miscellaneous equipment, will cost approximately $18,000, exclusive of the grading, unloading, and hauling equipment. An industrial railway outfit, consisting of a four-sack mixer, unloading crane and clamshell bucket, 4 miles of industrial track, 60 industrial cars, 120 batch boxes, 4 gasoline locomotives, road rollers, subgrade planer, water pump, pipe, forms, and all other miscellaneous equipment, will cost approximately $75,000, exclusive of the grading equipment. The magnitude of this expenditure makes it imperative that considerable thought should be given to the selection of equipment and that a well-balanced outfit be secured.

CAPITAL REQUIRED.

The amount of capital required to carry on concrete-pavement construction depends almost wholly on the size of the project. As a general rule, the amount of working capital required after the equipment has been secured will vary from 5 to 10 per cent of the total amount of the contract. A small project will require a larger percentage of working capital than a large one; so that while a working capital of 10 per cent or over might be required on a comparatively small project, a relatively large project can often be handled with a working capital as low as 5 per cent of the contract total. The usual method of paying for the work provides for semimonthly or monthly estimates to the contractor based upon the amount of work done, from which a nominal percentage is withheld until the completion of the work. Ordinarily this method should enable the contractor to meet most of his bills for labor and materials after the first two or three estimates are paid. The amount of working capital required also depends to a considerable extent upon the quantities of materials maintained in storage. Some storage of materials is nearly always necessary and it is especially desirable that these materials be stored during the off season. The storage of a large quantity of materials usually requires an outlay of capital greater than the average pavement contractor can afford to make. The buyers of the pavement, however, whether State or local subdivision, can relieve the contractor of the burden of carrying stored materials by paying for materials delivered and placed in storage. This policy enables the contractor to secure storage of materials at the cost of unloading, and by encouraging such storage the time of completion of the work is generally hastened, benefiting both the State and the contractor. This policy is recommended.

COST OF CONCRETE PAVEMENTS.

The cost of concrete pavements depends upon the amount of grading necessary, the number and size of culverts required, the cost of

cement and the aggregates, the price and efficiency of labor, and the nearness of the work to the unloading stations. These factors are entirely dependent upon the location of the work and are seldom exactly the same even for two projects in the same locality.

The most satisfactory method of arriving at the probable cost of a proposed pavement is first to ascertain by survey the amount of the various kinds of work to be done and the quantities of the materials required. An itemized estimate based on these quantities and the unit costs which prevail in the community for such work and materials may then be made. An intelligent estimate of cost requires considerable experience and knowledge of construction work. An estimate prepared without this knowledge represents nothing more than a blind guess. No attempt will be made to outline the procedure followed in making estimates of cost, because the subject can not be handled briefly. Following is the list of items included in a cost estimate form for one-course concrete pavement construction suggested by the Wisconsin Highway Commission. A number of these items frequently are overlooked in preparing estimates.

Item.	Operation.
Cost of sidings and moving equipment to job.	(*a*) Hauling and loading mixer, clamshell, pipe, pump, tools, camp equipment, industrial equipment, teams, trucks, etc. (*b*) Freight on above. (*c*) Unloading and hauling to job. (*d*) Moving overhead (other than rail shipment). (*e*) Cost of erection of camp, including water supply, storage bins, derrick, etc. (*f*) Return of above equipment to storage. (Note.—Item (*f*) is applicable only to job requiring whole season for completion or on last job of season.)
Lost time in moving equipment....	Number days ......, at ...... per day. (Lost time to include time lost in transit to job, between jobs, or between different set-ups on same job.)
Cement..................................	Number barrels in pavement. Cost per barrel f. o. b. destination. Cost of ...... barrels, at ...... per barrel. Cost of unloading, hauling, and covering. Cost of storing and rehandling ...... barrels. Insurance on stored cement and empty sacks. Sack loss. Freight return on empty sacks. Demurrage. Total cost of cement.
Clamshell and derrick supplies.....	Fuel, oil, etc., only. (Do not include repairs.)
Fine aggregate........................	Number of cubic yards including waste. Cost per ton at pit or quarry. Cost per cubic yard at pit or quarry. Freight per ton. Freight per cubic yard. Hauling cost per cubic yard. Estimated demurrage $.........., divided by total yardage gives cost per cubic yard. Cost rehandling from stock pile ......, divided by total yardage gives cost per cubic yard. Total cost per cubic yard on job.

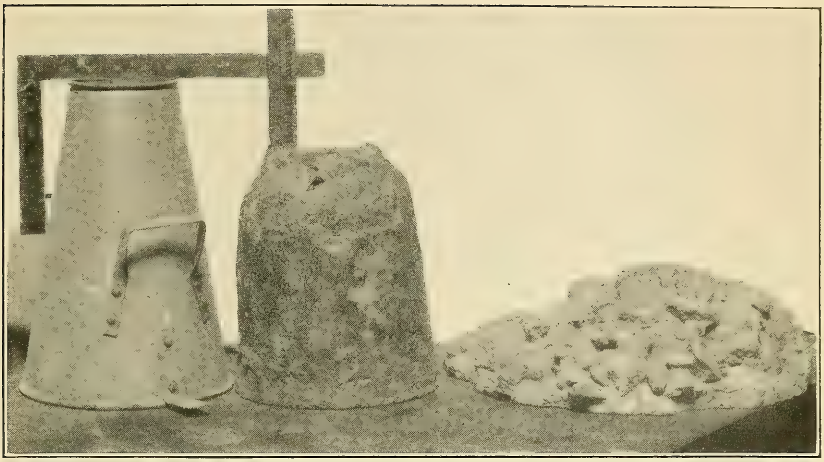


FIG. 1.—MEASURING THE CONSISTENCY OF CONCRETE BY THE SLUMP TEST. TOO MUCH WATER USED IN MIXING THE SPECIMEN AT THE RIGHT.

FIG. 2.—SUPER ELEVATED CURVE BEFORE THE CONSTRUCTION OF THE SHOULDERS.

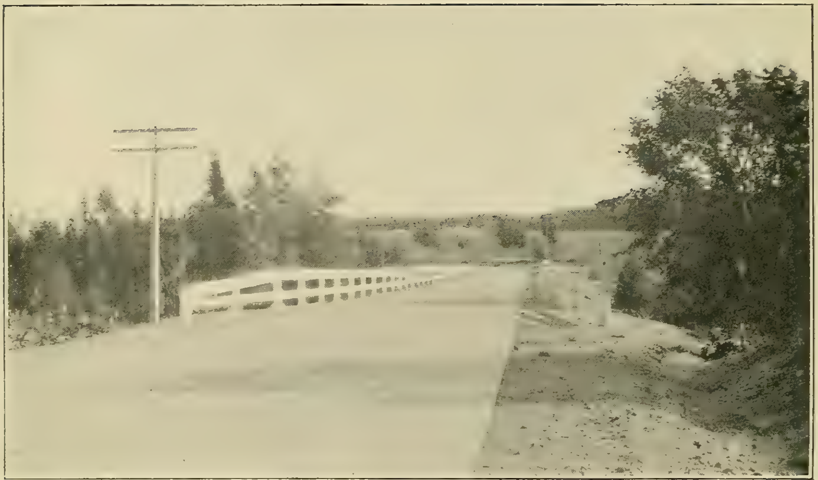


FIG. 1.—A FINISHED CONCRETE PAVEMENT.

FIG. 2.—FAILURE OF A THIN CONCRETE PAVEMENT UNDER HEAVY TRAFFIC.

Item	Operation.
Coarse aggregate	Number of cubic yards including waste. Cost per ton at pit or quarry. Cost per cubic yard at pit or quarry. Freight per ton. Freight per cubic yard. Hauling cost per cubic yard. Estimated demurrage $.........., divided by total yardage gives cos per cubic yard. Rehandling from stock pile per cubic yard. Total cost per cubic yard on job.
Surfacing	Preparation of subgrade. Cost of joint material on job. Cost of reinforcing metal on job. Labor, mixing, and placing concrete, including engineer, fireman, form setters, fine graders, wheelers, shovelers, cement men, puddlers, baling and sorting sacks, curing, covering, uncovering, finishers, water boy, watchmen, pump man, barricades, and lights. Cost of hauling mixed concrete, including fuel, and depreciation on hauling equipment. Water supply and pumping, including labor, connecting pipe, setting pump, fuel for pump, disconnecting pipe and drilling well. Mixer supplies, fuel and oil only. Miscellaneous supplies, such as boots, hardware, etc.
Camp loss	Including loss on board of men on operating days as well as on idle days, loss on full-time men not included in overhead, etc. (Do not include depreciation on camp equipment.)
Miscellaneous costs	(*a*) Cost of hiring and shipping in men. (*b*) Water rent. (*c*) Rent of grounds and buildings. (*d*) Cost of building cross-overs.
Contingencies	Delays due to railway embargoes, strikes at pits, quarry, or jobt material plant breakdown, machinery breakdown, failure of water supply, unusually bad weather, freezing of pipe line, etc.
Compensation and public liability insurance	
Bond cost	Personal or surety bonds.
Overhead	Per cent manager's yearly salary. Per cent yearly salary of stenographer and clerk. Per cent yearly salary material man and timekeeper. Per cent yearly expense of manager, including railway fare, hotel bills, bidding cost, auto, etc. Per cent yearly office rent. Per cent yearly office telephone and telegrams Per cent office supplies, miscellaneous. Corporation insurance. Interest on working capital not otherwise included Association dues.
Profit	
Charges for machinery and equipment	

For the benefit of those who may desire to have some idea of the cost of concrete pavements, a table has been prepared showing the weighted average cost per square yard and per mile of all Federal-aid concrete pavements contracted for or constructed in each of the States during the years 1919 and 1920. The costs per mile are based on a uniform width of 18 feet. The figures given are for the con-

crete pavement only and do not include the cost of grading, culverts, or bridges. This tabulation is given in the appendix, pages 64 to 66. In considering the costs given in these tables it should be borne in mind that the 1920 prices probably represent the peak of war prices.

MAINTENANCE.

The shoulders, slopes, and drainage structures of concrete roads require the same kind of maintenance as those of other types of improved roads. The maintenance of the pavement consists, for the most part, in repairing cup holes, cracks, joints, and perhaps the renewal of an occasional defective area. Cup holes are spots in the surface of the pavement which break down under traffic and which may result from a number of causes. The most frequent cause of such defects is the presence of sticks, lumps of clay, particles of unsound stone, or other soft material in the aggregates. When cup holes first appear they are usually from 1 to 2 inches in diameter and from $\frac{1}{2}$ to 1 inch in depth, but they are gradually enlarged by the action of traffic, which loosens the concrete around their edges, and unless promptly repaired they may soon have an area of several square feet and a considerable depth. The action of traffic also gradually breaks away the concrete at the edges of cracks and joints, and if proper maintenance is not provided a considerable area of the surface of the pavement will be destroyed. The maintenance of cup holes, cracks, and joints usually consists of filling them with tar or asphalt and covering the bituminous material with coarse sand, pea gravel, or stone chips. Satisfactory results can be secured by this method only when a crew with proper equipment and materials goes over the road, making the necessary repairs at least once and preferably twice a year.

Where defects of any considerable size are to be repaired the edges should be chiseled down until they are approximately vertical and not less than 1 inch deep. The hole should be thoroughly cleaned and painted with tar or asphalt, after which it should be filled with clean, coarse stone chips, thoroughly grouted with tar or asphalt. The surface of the patch should then be covered with coarse sand, pea gravel, or fine stone chips. A cold mix of small stone and bituminous material has sometimes been successfully used for this type of repair work.

Either tar or asphalt may be used for making such repairs. Satisfactory results have been obtained with each. There is some difference of opinion among engineers as to just what consistency the tar should possess in order to give the best results, but the most general requirement in this particular seems to be that the tar when subjected to the float test in water at 50° C. will permit the float to sink

in about 100 seconds. In order to apply a tar of this kind satisfactorily, it is necessary that it be heated to about 225° F.

The repair equipment may consist of a small portable tar kettle, a light truck, pouring pots, wire brooms, hammers, and stone chisels. The tar kettle is usually hauled by attaching it to the rear of the truck.

When it becomes necessary to renew any portion of the pavement with concrete, that portion should be entirely closed to traffic, and the concrete should be mixed, placed, and cured in the same way as a new pavement. The edges of the old concrete should be thoroughly cleaned and coated with neat cement mortar before the new concrete is placed.

A properly constructed concrete pavement ought to wear down uniformly and develop few defects. Poorly constructed and poorly maintained joints are probably responsible for more defects of the kind described than can be attributed to any other one cause. For this reason the joints should receive very careful attention at the time of construction.

RESURFACING OLD CONCRETE PAVEMENTS.

Under certain traffic conditions it may be necessary at tmes to resurface old concrete pavements so as to provide an additional thickness of pavement for the increased traffic. The thickness of the resurfacing layer should be not less than 3 or 4 inches at any point, and the concrete should be mixed in the proportions of 1 : 1½ : 3, using a coarse aggregate graded from ¼ inch to 1½ inches in size. Steel reinforcement weighing at least 25 pounds per 100 square feet, placed in the middle of the resurfacing layer, should preferably be used where the resurfacing is to be 3 inches thick. If the resurfacing layer is to be 4 inches thick, it is not believed that any reinforcement is necessary. Where an old concrete pavement is to be resurfaced, it should be thoroughly cleaned and all the bituminous filling used to cover cracks and small holes removed. The new concrete is placed and finished in the manner previously described for concrete pavements. Joints should be provided in the resurfacing layer directly over those in pavement below. The service records of a number of resurfaced concrete pavements indicate that it is immaterial whether or not a bond is secured between the two layers of the concrete.

APPENDIX.

A. QUANTITIES OF MATERIALS REQUIRED FOR CONCRETE PAVEMENTS.

1 : 1½ : 3 mix.

Per cubic yard {Cement .... 1.91 bbls.
Fine aggregate .... .40 cu. yd.
Coarse aggregate .. .81 cu. yd.

Fine aggregate .... 0″ to ¼″
Coarse aggregate .. ¼″ to 1½″

Width.	Thickness.		Area.		Quantities per lineal foot.[1]				Quantities per mile.[1]			
	Edge.	Center.	Per linear foot.	Per mile.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.
Feet.	*In.*	*In.*	*Sq. yds.*	*Sq. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*
9	6	[2] 8	1.000	5,280	0.204	0.389	0.081	0.165	1,077	2,057	431	872
9	7	[2] 8	1.000	5,280	.213	.407	.085	.172	1,124	2,147	450	910
9	6	6	1.000	5,280	.167	.319	.067	.135	881	1,683	352	713
9	7	7	1.000	5,280	.194	.371	.078	.157	1,024	1,956	410	829
9	8	8	1.000	5,280	.222	.424	.089	.180	1,172	2,238	469	949
10	7	8	1.111	5,866	.237	.453	.095	.192	1,251	2,389	500	1,013
10	6	6	1.111	5,866	.185	.353	.074	.150	977	1,867	391	792
10	7	7	1.111	5,866	.216	.413	.086	.175	1,141	2,179	456	924
10	8	8	1.111	5,866	.247	.472	.099	.200	1,304	2,490	521	1,056
16	6	8	1.777	9,383	.361	.690	.144	.292	1,906	3,640	762	1,544
16	7	8	1.777	9,383	.378	.722	.151	.306	1,997	3,814	799	1,617
16	6	6	1.777	9,383	.296	.565	.118	.240	1,563	2,985	625	1,267
16	7	7	1.777	9,383	.346	.661	.138	.280	1,827	3,489	730	1,480
16	8	8	1.777	9,383	.395	.754	.158	.320	2,086	3,984	834	1,689
18	6	8	2.000	10,560	.407	.778	.163	.330	2,149	4,105	860	1,741
18	7	8	2.000	10,560	.426	.814	.170	.345	2,249	4,295	900	1,822
18	6	6	2.000	10,560	.333	.637	.133	.270	1,758	3,358	703	1,424
18	7	7	2.000	10,560	.389	.743	.156	.315	2,053	3,921	821	1,663
18	8	8	2.000	10,560	.444	.849	.178	.360	2,344	4,477	938	1,898
20	6	8	2.222	11,732	.453	.865	.181	.367	2,392	4,569	957	1,938
20	7	8	2.222	11,732	.473	.904	.189	.383	2,498	4,771	999	2,023
20	7	7	2.222	11,732	.432	.825	.173	.350	2,281	4,357	912	1,848
20	8	8	2.222	11,732	.494	.943	.198	.400	2,608	4,981	1,043	2,112
20	9	9	2.222	11,732	.555	1.061	.222	.450	2,930	5,596	1,172	2,373

1 : 2 : 3 mix.

Per cubic yard {Cement .... 1.74 bbls
Fine aggregate .... .49 cu. yd.
Coarse aggregate .. .74 cu. yd.

Fine aggregate .... 0″ to ¼″
Coarse aggregate .. ¼″ to 2″

9	6	[2] 8	1.000	5,280	0.204	0.355	0.100	0.151	1,077	1,874	528	797
9	7	[2] 8	1.000	5,280	.213	.370	.104	.158	1,124	1,956	551	832
9	6	6	1.000	5,280	.167	.290	.082	.123	881	1,533	431	652
9	7	7	1.000	5,280	.194	.338	.095	.144	1,024	1,782	502	758
9	8	8	1.000	5,280	.222	.387	.109	.164	1,172	2,039	574	867
10	7	8	1.111	5,866	.237	.412	.116	.175	1,251	2,177	613	926
10	6	6	1.111	5,866	.185	.322	.091	.137	977	1,700	479	723
10	7	7	1.111	5,866	.216	.376	.106	.160	1,141	1,985	559	844
10	8	8	1.111	5,866	.247	.430	.121	.183	1,304	2,269	639	965
16	6	8	1.777	9,383	.361	.628	.177	.267	1,906	3,316	934	1,410
16	7	8	1.777	9,383	.378	.658	.185	.280	1,997	3,475	979	1,478
16	6	6	1.777	9,383	.296	.516	.145	.219	1,563	2,720	766	1,157
16	7	7	1.777	9,383	.346	.602	.169	.256	1,827	3,179	895	1,352
16	8	8	1.777	9,383	.395	.687	.194	.292	2,086	3,629	1,022	1,544
18	6	8	2.000	10,560	.407	.709	.200	.301	2,149	3,739	1,053	1,590
18	7	8	2.000	10,560	.426	.741	.209	.315	2,249	3,913	1,102	1,664
18	6	6	2.000	10,560	.333	.580	.163	.247	1,758	3,059	861	1,301
18	7	7	2.000	10,560	.389	.677	.191	.288	2,053	3,572	1,006	1,519
18	8	8	2.000	10,560	.444	.773	.218	.329	2,344	4,078	1,148	1,735
20	6	8	2.222	11,732	.453	.788	.222	.335	2,392	4,162	1,172	1,770
20	7	8	2.222	11,732	.473	.823	.232	.350	2,498	4,346	1,224	1,849
20	7	7	2.222	11,732	.432	.752	.212	.320	2,281	3,969	1,118	1,688
20	8	8	2.222	11,732	.494	.859	.242	.365	2,608	4,537	1,278	1,930
20	9	9	2.222	11,732	.555	.967	.272	.411	2,930	5,098	1,436	2,168

[1] Quantities given are the theoretical quantities required. In actual practice an allowance must be made for loss in handling.
[2] For pavement on one side of center line, one-way crown.

A. QUANTITIES OF MATERIALS REQUIRED FOR CONCRETE PAVEMENTS—Continued.

1 : 2 : 3½ Mix.

Per cubic yard { Cement............ 1.61 bbls. / Fine aggregate.... .45 cu. yd. / Coarse aggregate.. .79 cu. yd.

Fine aggregate....0″ to ¼″
Coarse aggregate..¼″ to 2½″

Width.	Thickness.		Area.		Quantities per lineal foot.[1]				Quantities per mile.[1]			
	Edge.	Center.	Per linear foot.	Per mile.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.
Feet.	*In.*	*In.*	*Sq. yds.*	*Sq. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*
9......	6	[2]8	1.000	5,280	0.204	0.328	0.092	0.161	1,077	1,734	484	850
9......	7	[2]8	1.000	5,280	.213	.343	.096	.168	1,124	1,809	506	888
9......	6	6	1.000	5,280	.167	.268	.075	.132	881	1,418	396	696
9......	7	7	1.000	5,280	.194	.312	.087	.153	1,024	1,648	461	809
9......	8	8	1.000	5,280	.222	.357	.100	.175	1,172	1,887	527	926
10......	7	8	1.111	5,866	.237	.381	.107	.187	1,251	2,014	563	988
10......	6	6	1.111	5,866	.185	.298	.083	.146	977	1,573	440	772
10......	7	7	1.111	5,866	.216	.348	.097	.171	1,141	1,837	513	901
10......	8	8	1.111	5,866	.247	.398	.111	.195	1,304	2,099	587	1,030
16......	6	8	1.777	9,383	.361	.581	.162	.285	1,906	3,069	858	1,506
16......	7	8	1.777	9,383	.378	.609	.170	.299	1,997	3,215	899	1,577
16......	6	6	1.777	9,383	.296	.477	.133	.234	1,563	2,516	704	1,235
16......	7	7	1.777	9,383	.346	.557	.156	.273	1,827	2,941	822	1,443
16......	8	8	1.777	9,383	.395	.636	.178	.312	2,086	3,358	938	1,647
18......	6	8	2.000	10,560	.407	.655	.183	.322	2,149	3,460	967	1,698
18......	7	8	2.000	10,560	.426	.686	.192	.336	2,249	3,620	1,012	1,776
18......	6	6	2.000	10,560	.333	.536	.150	.263	1,758	2,830	791	1,389
18......	7	7	2.000	10,560	.389	.626	.175	.307	2,053	3,305	923	1,621
18......	8	8	2.000	10,560	.444	.715	.200	.351	2,344	3,773	1,055	1,852
20......	6	8	2.222	11,732	.453	.729	.204	.358	2,392	3,851	1,076	1,889
20......	7	8	2.222	11,732	.473	.762	.213	.374	2,498	4,022	1,124	1,974
20......	7	7	2.222	11,732	.432	.696	.194	.341	2,281	3,673	1,026	1,802
20......	8	8	2.222	11,732	.494	.795	.222	.390	2,608	4,199	1,173	2,060
20......	9	9	2.222	11,732	.555	.894	.250	.438	2,930	4,717	1,318	2,314

1 : 2 : 4 Mix.

Per cubic yard { Cement............ 1.50 bbls. / Fine aggregate.... .42 cu. yd. / Coarse aggregate.. .84 cu. yd.

Fine aggregate....0″ to ¼″
Coarse aggregate..¼″ to 2½″

9......	6	[2]8	1.000	5,280	0.204	0.306	0.086	0.172	1,077	1,615	452	904
9......	7	[2]8	1.000	5,280	.213	.319	.089	.178	1,124	1,686	472	944
9......	6	6	1.000	5.280	.167	.250	.070	.140	881	1,321	370	740
9......	7	7	1.000	5,280	.194	.291	.082	.164	1,024	1,536	430	860
9......	8	8	1.000	5,280	.222	.333	.093	.186	1,172	1,758	492	984
10......	7	8	1.111	5,866	.237	.355	.099	.198	1,251	1,876	525	1,050
10......	6	6	1.111	5,866	.185	.278	.078	.156	977	1,466	410	820
10......	7	7	1.111	5,866	.216	.324	.091	.182	1,141	1,711	479	958
10......	8	8	1.111	5,866	.247	.370	.104	.208	1,304	1,956	548	1,096
16......	6	8	1.777	9,383	.361	.541	.152	.304	1,906	2,859	801	1,602
16......	7	8	1.777	9,383	.378	.567	.159	.318	1,997	2,995	839	1,678
16......	6	6	1.777	9,383	.296	.444	.124	.248	1,563	2,345	657	1,314
16......	7	7	1.777	9,383	.346	.519	.145	.290	1,827	2,741	767	1,534
16......	8	8	1.777	9,383	.395	.593	.166	.332	2,086	3,129	876	1,752
18......	6	8	2.000	10,560	.407	.611	.171	.342	2,149	3,224	903	1,806
18......	7	8	2.000	10,560	.426	.639	.179	.358	2,249	3,373	945	1,890
18......	6	6	2.000	10,560	.333	.500	.140	.280	1,758	2,637	738	1,476
18......	7	7	2.000	10,560	.389	.583	.163	.326	2,053	3,079	862	1,724
18......	8	8	2.000	10,560	.444	.667	.187	.374	2,344	3,516	984	1,968
20......	6	8	2.222	11,732	.453	.679	.190	.380	2,392	3,588	1,004	2,008
20......	7	8	2.222	11,732	.473	.710	.198	.396	2,498	3,747	1,049	2,098
20......	7	7	2.222	11,732	.432	.648	.181	.362	2,281	3,421	958	1,916
20......	8	8	2.222	11,732	.494	.741	.207	.414	2,608	3,912	1,095	2,190
20......	9	9	2.222	11,732	.555	.833	.233	.466	2,930	4,395	1,231	2,462

[1] Quantities given are the theoretical quantities required. In actual practice an allowance must be made for loss in handling.
[2] For pavement on one side of center line, one-way crown.

B. TABLES FOR DETERMINING THE SIZE OF PUMP REQUIRED FOR DELIVERING WATER.[1]

Loss in Friction Head.

Water required per minute.	Friction head in 2-inch pipe—			
	1 mile.	2 miles.	3 miles.	4 miles.
	Feet.	*Feet.*	*Feet.*	*Feet.*
20 gallons	51	102	153	204
30 gallons	110	220	330	440
40 gallons	194	388	582	776
50 gallons	296	592	888	1,184
60 gallons	468	936	1,404	1,872

[1] From an article by Clyde E. Learned, Highway Engineer, Bureau of Public Roads, published in Public Roads, June, 1919.

To the loss in head in the above table it will be necessary to add the vertical height that the water is to be pumped and to make allowance for angles and valves.

The theoretical horsepower required to furnish water under different heads is given in the following table:

Theoretical Horsepower Required.

Water required per minute.	Total head.[1]					
	100 feet.	200 feet.	300 feet.	400 feet.	500 feet.	600 feet.
	Horse-power.	*Horse-power.*	*Horse-power.*	*Horse-power.*	*Horse-power.*	*Horse-power.*
20 gallons	0.50	1.00	1.50	2.00	2.50	3.00
30 gallons	0.75	1.50	2.25	3.00	3.75	4.50
40 gallons	1.00	2.00	3.00	4.00	5.00	6.00
50 gallons	1.25	2.50	3.75	5.00	6.25	7.50
60 gallons	1.50	3.00	4.50	6.00	7.50	9.00

[1] Total head required equals friction head, plus height to be raised, plus loss of head in valves, elbows, etc.

Multiply the theoretical horsepower by 4 for deliveries of 30 gallons per minute or less and by 3 for deliveries of from 30 to 125 gallons per minute.

Example.—Required, 40 gallons per minute; maximum distance to be pumped, 2 miles up a hill 100 feet in height.

From first table:	Feet.
Loss in head in pipe line	388
Vertical height up hill	100
Estimated loss of head in valves, elbows, etc	20
Total head	508
From second table:	Horsepower.
Theoretical horsepower required	5
Actual horsepower required for engine and pump, three times theoretical horsepower	15

C. COST OF FEDERAL-AID CONCRETE PAVEMENTS.

Plain Concrete Pavements.

State.	1919				1920				Cost per mile for 18-foot pavement only, based on these prices.	
	Total area awarded or built.	Average price per square yard.	Mix.	Cross-section.	Total area awarded or built.	Average price per square yard.	Mix.	Cross-section.	1919	1920
	Sq. yds.				*Sq. yds.*					
Arizona	41,416	$1.65	1:2 :3½	5-" uniform thickness	187,174	$2.43	1:2 :3½	6" uniform thickness	$17,424	$25,661
Arkansas	81,198	3.00	1:2 :3	8" center, 7" edges					31,680	
California	414,010	1.69	1:2 :4	4" uniform thickness	119,834	1.91	1:2 :4	4½" uniform thickness	17,846	20,170
Do	173,760	2.48	1:2 :4	6" uniform thickness					26,189	
Colorado	114,338	2.51	1:2 :3	7½" center, 6" edges	337,379	2.89	1:2 :3	7½" center, 6" edges	26,506	30,518
Connecticut					360,460	2.74	1:2 :4	8¼" inch center, 6" edges		28,934
Delaware	63,622	5.21	1:2 :4	8" center, 6" edges					55,018	
Georgia					46,189	3.20	1:2 :4	6" center, 5" edges		33,792
Do					154,307	3.17	1:2 :4	6" uniform thickness		33,475
Do					34,914	2.81	1:2 :3	do		29,674
Do					106,930	2.58	1:2 :3	6½" uniform thickness		27,245
Do					69,844	2.48	1:2 :4	6½" center, 6" edges		26,189
Do					26,078	2.50	1:2 :4	7" center, 5" edges		26,400
Do					27,950	2.38	1:2½:5	do		25,133
Do					95,275	2.45	1:2 :3	7" center, 6" edges		25,872
Do					26,036	2.78	1:2 :4	8" center, 6" edges		29,357
Do					140,739	3.00	1:2 :3	do		31,680
Idaho					73,920	3.095	1:2 :3	6½" center, 5½" edges		32,683
Illinois	4,902,991	2.53	1:2 :3½	8" center, 7" edges	362,607	3.11	1:2 :3½	8" uniform thickness	26,717	32,842
Indiana	1,296,391	2.69	1:1½:3	8" center, 6" edges					28,406	
Kansas	169,632	2.88	1:2 :3½	do	235,878	3.60	1:2 :3½	8" center, 6" edges	30,413	38,016
Kentucky	67,324	2.54	1:2 :3	do					26,822	
Maine					48,218	1.89	1:2 :3½	8" center, 6" edges		19,958
Do					76,286	1.73	1:2 :3½	9" center, 7" edges		18,269
Maryland	662,860	2.36	1:2 :4	8" center, 6" edges	38,270	2.81	1:2 :4	8" center, 6" edges	24,922	29,674
Massachusetts	175,032	2.15	1:2 :4	7¼" center, 5" edges	66,320	2.55	1:2 :4	7¼" center, 5" edges	22,704	26,928
Do	56,313	2.17	1:2 :4	6" unifrom thickness	9,246	3.29	1:2 :4	8" center, 6" edges	22,915	34,742
Do	79,744	2.44	1:2 :4	8¼' center, 6 ' edges					25,766	
Michigan	290,892	2.36	1:1½:3	8" center, 6" edges	147,287	3.05	1:1½:3	8" center, 6" edges	24,922	32,208
Minnesota	740,713	2.32	1:2 :4	7½" center, 6½" edges	294,244	3.23	1:2 :4	7½" center, 6½" edges	24,499	34,109
Mississippi					27,920	2.99	1:2 :3	8¼" center, 6" edges		31,574
Missouri	63,976	1.75	1:2 :3	8" center, 6" edges	626,825	3.08	1:2 :3	8" center, 6" edges	18,480	32,525
Do					95,677	3.50	1:2 :3	8" uniform thickness		36,960
Montana					289,661	2.52	1:2 :3	8" center, 6" edges		26,611
Nebraska	62,606	2.72	[1] 1:3	8" center, 6" edges	18,705	3.85	[1] 1:3	do	28,723	40,656
Nevada	70,960	2.33	1:2 :4	6" uniforn thickness	144,315	3.33	1:2 :4	6" uniform thickness	24,605	35,165

New Jersey	41,453	2.31	1:1½:3	8½″ center, 6″ edges	48,866	3.10	1:1½:3	8½″ center, 6″ edges	24,394	32,736
Do	62,107	2.53	1:2 :3	8″ center, 6″ edges	97,119	3.68	1:1½:3	8¾″ center, 6″ edges	26,717	38,861
Do	95,867	2.93	1:2 :3	8½″ center, 6″ edges	28,737	3.99	1:1½:3	10½″ center, 8″ edges	30,941	42,134
Do	263,035	2.66	1:2 :3	8¾″ center, 6″ edges	18,627	3.90	1:2 :3	do	28,090	41,184
Do	128,031	3.14	1:2 :3	10½″ center, 8″ edges					33,158	
New Mexico					210,450	2.30	1:2 :3	7″ center, 5″ edges		24,288
New York	226,887	2.24	1:1½:3	7″ center, 5″ edges					23,654	
North Carolina	87,770	2.76	1:1½:3	8″ center, 6″ edges	165,609	3.11	1:1½:3	8″ center, 6″ edges	29,146	32,842
Ohio	134,052	2.64	1:1½:3	do					27,878	
Do	106,189	2.91	1:1½:3	8½″ center, 6½″ edges					30,730	
Do	551,165	2.79	1:1½:3	9″ center, 7″ edges					29,462	
Do	67,014	3.08	1:1½:3	10″ center, 8″ edges					32,525	
Oklahoma	480,108	2.41	1:2 :3	8½″ center, 6¼″ edges	18,076	3.45	1:2 :3	7″ uniform thickness	25,450	36,432
Oregon					83,048	2.74	1:2 :3	6½″ center, 5½″ edges		28,934
Rhode Island					25,523	2.77	1:2 :3	8½″ center, 6″ edges		29,251
South Carolina	53,159	1.19	1:2 :4	7″ center, 5″ edges	125,480	3.29	1:2 :4	8″ center, 6″ edges	12,566	34,742
Do	12,222	1.45	1:2 :4	8″ center, 5½″ edges					15,312	
Tennessee	22,000	1.23	1:2 :3	7½″ center, 6 edges	95,012	2.90	1:2 :3	7½ center, 6″ edges	12,989	30,624
Texas	15,721	2.87	1:2 :3	7″ center, 5″ edges	5,483	3.30	1:2 :3	7″ center 5″ edges	30,307	34,848
Do	107,260	2.65	1:2 :3½	8″ center, 6″ edges	88,479	3.25	1:2 :3½	do	27,984	34,320
Do	3,396	2.85	1:2 :3	8″ center, 7″ edges	46,498	3.50	1:2 :3	7½″ center, 6″ edges	30,096	36,960
Utah					131,790	2.79	1:2 :3	8″ center, 6″ edges		29,462
Vermont	14,636	2.73	1:2 :3	8″ center, 6″ edges					28,829	
Virginia	161,332	2.36	1:2 :4	7″ center, 5″ edges	251,600	3.07	1:2 :4	7″ center, 5″ edges	24,922	32,419
Do					65,160	3.15	1:2 :4	8″ center, 6″ edges		33,264
Washington	803,929	2.29	1:2 :3	7½″ center, 6″ edges	413,721	2.50	1:2 :3	7½″ center, 6″ edges	24,182	26,400
West Virginia	94,714	2.30	1:2 :4	8″ center, 6″ edges	42,399	3.23	1:1½:3	8″ center, 6″ edges	24,288	34,109
Do	101,445	2.83	1:1½:3	do					29,885	
Wisconsin	651,957	2.03	1:2 :3½	8″ center, 7″ edges	597,957	2.75	1:2 :3½	8″ center, 7″ edges	21,437	29,040
Wyoming					14,900	2.90	1:2 :3	7″ center, 5½″ edges		30,624
	13,813,257	2.477	All mixes.	All sections	6,665,572	2.913	All mixes	All sections	26,157	30,761

[1] Combined sand-gravel aggregate.

D. COST OF FEDERAL-AID CONCRETE PAVEMENTS—Continued.

Two-Course Concrete Pavements.[1]

State.	1919					1920					Cost per mile for 18-foot pavement only—Based on these prices.	
	Total area awarded or built.	Average price per square yard.	Mix.		Cross-section.	Total area awarded or built.	Average price per square yard.	Mix.		Cross-section.	1919	1920
			Top.	Base.				Top.	Base.			
	Sq. yds.					*Sq. yds.*						
Florida	16,104	$2.51	1:2 :3	1:3 :6	6″ uniform thickness	13,200	$2.53	1:2 :3	1:3 :6	7″ center, 6″ edges	$26,506	$26,717
Do	20,750	2.505	1:2 :3	1:3 :6	7″ center, 6″ edges						26,453	
Kansas	490,994	2.71	1:1½:2½	1:2½:4	8 center, 6″ edges	355,040	3.53	1:1½:2½	1:2½:4	8″ center, 6″ edges	28,934	37,277
Do						47,974	3.70	1:1½:2½	1:2½:4	8½″ center, 7″ edges		39,072
Missouri	142,666	2.75	1:2 :3	1:3 :5	8″ centers, 6″ edges	20,713	3.60	1:2 :3	1:3 :5	9″ center, 7½″ edges	29,040	38,016
Texas	31,766	2.73	1:3½	1:7½	7⅔″ center, 6″ edges	155,872	2.65	1:2 :3	1:3 :6	7½″ center, 6½″ edges	28,829	27,984
Do	46,800	2.82	1:3½	1:7½	8⅔″ center, 7″ edges						29,779	
	749,030	2.735	All mixes		All sections	592,799	3.292	All mixes		All sections	28,882	34,764

[1] No work of this type awarded in States not listed in tabulation.

D. COST OF FEDERAL-AID CONCRETE PAVEMENTS—Continued.

Reinforced Concrete Pavements.[1]

State.	1919					1920					Cost per mile for 18-foot pavement only—Based on these prices.	
	Total area awarded or built.	Average price per square yard, including reinforcement.	Mix.	Reinforcement per square yard.	Cross-section.	Total area awarded or built.	Average price per square yard, including reinforcement.	Mix.	Reinforcement per square yard.	Cross-section.	1919	1920
	Sq. yds.			*Pounds.*		*Sq. yds.*			*Pounds.*			
California	47,843	$2.58	1:2:4	3.47	4″ uniform thickness	315,652	$2.26	1:2:4	3.47	4″ uniform thickness	$27,245	$23,866
Do	209,949	2.57	1:2:4	3.47	5″ uniform thickness	94,248	2.25	1:2:4	3.47	5″ uniform thickness	27,139	23,760
Iowa	79,184	3.59	1:2:3½	1.88	8″ center, 7″ edges	1,366,231	3.99	1:2:3½	1.88	8″ center, 7″ edges	37,910	42,134
Do						94,837	3.76	1:2:3½	2.50	8″ uniform thickness		39,706
Kentucky						78,290	2.94	1:2:3	3.60	8″ center, 6″ edges		31,046
Montana						20,178	2.80	1:2:3	2.50	6″ uniform thickness		29,568
New York	125,343	2.52	1:1½:3	1.95	7″ center, 5″ edges						26,611	
North Carolina	11,350	3.20	1:1½:3	7.65	9¼″ center, 7″ edges						33,792	
Ohio	163,957	2.78	1:1½:3	2.60	8″ center, 6″ edges						29,357	
Do	194,188	3.75	1:1½:3	2.60	10″ center, 8″ edges						39,600	
Oregon						60,845	3.19	1:2:3	2.90	7″ uniform thickness		33,686
Pennsylvania	2,721,627	2.83	1:2:3	2.25	8″ center, 6″ edges	1,435,122	4.08	1:2:3	2.25	8″ center, 6″ edges	29,885	43,085
Texas	24,404	3.60	1:2:3	2.70	7″ center, 5″ edges	11,017	4.22	1:2:3	2.25	7″ center, 5″ edges	38,016	44,563
Do	28,000	2.93	1:3⅓ top. 1:7½ base.	1.98	7⅔″ center, 6″ edges	28,913	3.54	1:2:3	2.25	8″ center, 6″ edges	30,941	37,382
Do	30,605	2.85	1:2:3½	2.25	8″ center, 6″ edges	64,425	4.03	1:2:3	2.25	9″ center, 7″ edges	30,096	42,557
Washington	88,579	2.67	1:2:3	2.98	7½″ center, 6″ edges	26,436	2.88	1:2:3	3.93	7½″ center, 6″ edges	28,195	30,413
West Virginia						19,911	3.48	1:1½:3	2.25	do		36,749
Wisconsin	9,542	1.95	1:2:3½	3.60	7″ uniform thickness	15,895	2.83	1:2:3½	3.60	7″ uniform thickness	20,592	29,885
	3,734,571	2.864	All mixes		All sections.	3,632,000	3.763	All mixes.		All sections.	30,244	39,737

[1] No work of this type awarded in States not listed in tabulation.

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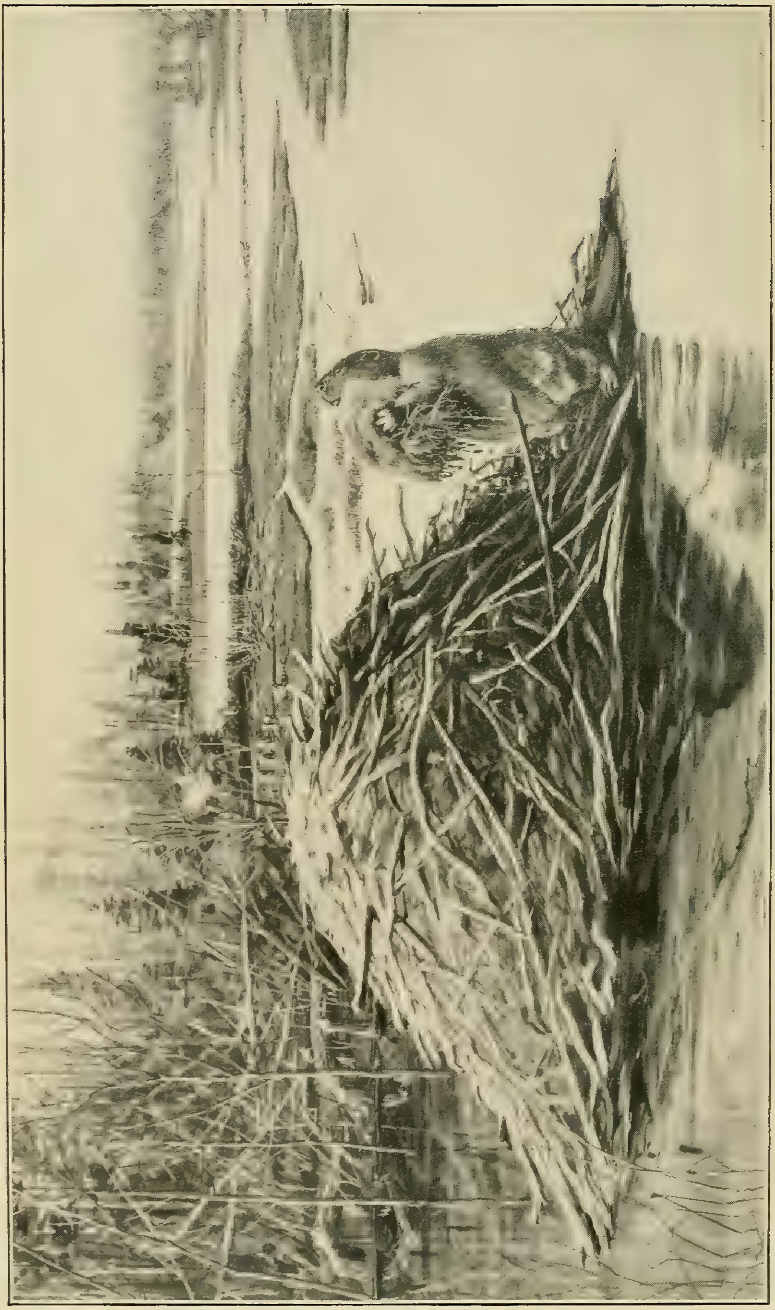

B1879M

BEAVER HOUSE IN PROCESS OF CONSTRUCTION.

Considerable skill and energy are required by the beaver to climb in an upright position to the point where the load of building material carried is to be deposited.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1078

Washington, D. C. ▼ October 18, 1922

BEAVER HABITS, BEAVER CONTROL, AND POSSIBILITIES IN BEAVER FARMING.

By VERNON BAILEY, *Chief Field Naturalist, Division of Biological Investigations, Bureau of Biological Survey.*

CONTENTS.

INTRODUCTION.

Only two centuries ago beavers inhabited the greater part of the North American Continent and were to the native people an important source of food and warm clothing. Their fur soon attracted the white traders and trappers, and traffic in their skins became an important factor in promoting the early settlement of the country. Through the generations of intensive trapping that followed, the beavers were greatly reduced in numbers and restricted in range until they have been exterminated over much of their area. For the last 20 years they have been given special protection in many sections of the country and after being long absent have been restored to some parts of their old range, where under favorable conditions they have thrived and increased rapidly.

As a great part of the original range of the beaver is now under cultivation, and fields and orchards replace the primeval forests, it is obviously unwise to restore the animals to all of their original waters, but there are still many localities where they could be introduced without harm, and where, by storing water in the reservoirs along mountain streams, they would do great good in helping prevent

NOTE.—This bulletin discusses methods of dealing with beavers when their operations conflict with agriculture and other human activities, methods of transporting them to localities where they may be conserved as a valuable and interesting natural resource, and methods of utilizing them as an important supplement to the fur supply by establishing them in suitable climates, particularly in certain waste lands and other areas unsuited to agriculture.

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floods and extensive erosion, in increasing the stream flow in dry weather, and in improving the fishing resources of streams and lakes. In such places they would not only enrich our forests and parks with a unique and intensely interesting form of wild life, but would also add much valuable fur to our decreasing supply.

Even in the mountains and remote wildernesses, however, there are many localities where beavers, if allowed unrestricted freedom, would surely destroy much valuable timber, ruin many of the most attractive lake and stream borders, destroy trails and roads, and even endanger railroad beds and human lives. While interesting, desirable, and valuable animals in their place, they must be controlled to a certain extent or they will become exceedingly troublesome and destructive.

Beavers at one time produced fur of greater value than that of any other fur-bearing animal of North America. During the period when the fur traders dominated a vast region in the West and North, the beaver skin was the unit of value used in the traffic between the Indians and the white trappers. Through unrestricted trapping beavers were exterminated over great areas and for a time threatened with complete extinction, but with the protection given them in recent years they are now returning to many parts of their former range.

The necessary control of beavers in any part of the country need not be difficult, but must be based on a thorough knowledge of the animals and their habits. Controlling them under semidomestic conditions, in beaver farming as a business enterprise, has not yet been satisfactorily tested, but with our present knowledge of the habits of beavers there is every reason to believe that this may develop into a successful industry.

DISTRIBUTION.

Beavers originally occupied the streams of most of the continent of North America from the mouths of the Rio Grande and Colorado Rivers and northern Florida north to Labrador, Alaska, and the mouth of the Mackenzie, well within the Arctic Circle (Fig. 1). Over this enormous area they are exposed to a great variety of climatic and environmental conditions, which have produced numerous geographic races, or subspecies. These vary somewhat in size and proportions, but far more in the color, quality, and value of the fur. Generally they are paler in the south and darker in the north, but the darkest, most beautiful, and most valuable fur is found along the southern shore of Lake Superior.

DESCRIPTION.

Beavers have been directly responsible, in the construction of dams, for holding water in storage, preventing erosion, and profoundly af-

fecting the topography of vast areas through an unknown period. Before considering the question of controlling these natural engineers or of utilizing them in beaver farming, it is important to consider their physical character and remarkable habits.

FIG. 1.—Range of beavers and their principal food tree, the aspen. The beaver was one of the most widely distributed mammals in North America, as shown by the heavy line bordering its original range. It now occupies about half of its original territory. The aspen or poplar (*Populus tremuloides* and varieties) is the most widely distributed tree in North America, as shown by the shaded area on the map, filling the Canadian and Hudsonian Zones and overlapping slightly into the upper edge of the Transition Zone. It marks the area of suitable climate for beaver farming and furnishes the best beaver food.

GENERAL PHYSICAL CHARACTERISTICS.

Beavers are compact, heavy-bodied, strongly framed animals (Pl. II, Fig. 1) with powerfully developed bones and muscular systems, broadly flattened naked tails, and dense coats of fine, soft, waterproof underfur, hidden by coarse outer or guard hairs, generally of some shade of dull or rusty brown. The hind feet are large and the five long toes fully webbed for swimming, the two inner toes on each foot being provided with unique and remarkable combing claws; the front feet are small and unwebbed, and are used mainly as hands. The eyes are small, with very limited range of vision; the ears are short, fur lined, valvular (closing under water), and very keen of hearing; the nostrils are small and valvular, with large and complex nasal cavities lying back of the openings, and have an unusually keen sense of smell. The mouth also is valvular, with hairy lips closing perpendicularly back of the long protruding, chisellike incisors, so that the water does not enter the mouth when the incisors are used in cutting or tearing up roots or sticks under water. The genital organs also are well protected from the water, being concealed under the skin and opening into the general anal cloaca, so that the sexes are not easily determined by external examination, except in adult females, which have four conspicuous teats, two on each mammary gland. A pair each of large musk and oil glands lie under the skin of the belly just in front of the anal opening. The stomach and intestines are very large to accommodate the large quantity of coarse food consumed.

MEASUREMENTS AND WEIGHT.

A fair-sized, probably 3-year-old, female beaver, caught near Ashland, Wis., measured in total length 42.5 inches (1,080 millimeters), naked portion of the tail 11 inches (280 millimeters), the hind foot 7 inches (180 millimeters), and the length of the ear 1¼ inches (34 millimeters). The weight was 50 pounds. Two young about 2 weeks old weighed 1¾ and 2 pounds, respectively; yearling beavers weigh apparently 25 to 30 pounds; two-year-olds about 40 or 45 pounds; and three-year-olds probably 50 pounds. Old and large beavers reach a weight of 60 to 70 pounds, and there are records of old and very fat beavers weighing from 100 to 110 pounds.

INTELLIGENCE.

Beavers are widely famed woodcutters and builders, and while not endowed with the degree of human intelligence often ascribed to them, they are wonderfully expert along their own lines and quick to learn and apply new methods or to take warning from new

B23377

FIG. 1.—A 35-POUND BEAVER CAUGHT IN PITFALL.

This animal was comparatively gentle from the first.

B23420

FIG. 2.—YELLOW POPLARS CUT BY BEAVERS.

These trees, 12 inches in diameter, were cut at Brandreth Lake, N. Y. While aspens are the principal food trees of beavers, no distinction is made in varieties. The yellow poplar and even cottonwoods are eagerly accepted.

B23418

FIG. 1.—YELLOW BIRCH, 14 INCHES IN DIAMETER, CUT BY BEAVERS.

The branches of birches are used for food and building material if aspens are not to be had.

B20186

FIG. 2.—BEAVER CANAL.

This canal leads from the pond to the source of food supply and is used for floating wood to the dam and house. (Photograph by T. H. Scheffer.)

dangers. Patience, persistence, strength, and industry are more important factors in their work than quick wit or versatility.

DISPOSITION.

Among themselves beavers are generally friendly and sociable, at least in their own family and colony. The young are especially playful and affectionate with each other and with anyone so fortunate as to win their confidence. Strangers, whether beaver or human, are likely to be treated as enemies, and a strange beaver placed in an inclosure with others is sometimes attacked and even killed. The common belief that the young when 2 years old are driven away from the colony is quite likely without foundation. The dispersal of a colony is probably due to a decrease in the easily accessible food supply.

HABITS.

SWIMMING.

Both the form and the anatomy of beavers show the adaptation of the animals to life in the water rather than on land. They are powerful, easy, and graceful swimmers, though ordinarily not rapid, merely paddling along with the large webbed hind feet; but when alarmed they can swim under water at great speed, apparently as fast as an otter or seal and with a somewhat similar undulatory motion of body and tail, the tail appearing to be effective as a high-speed propeller.

The question, Why is a beaver's tail flat and wide? is often asked, but it is only necessary to see it in use, tilted up, steering one way or the other, or striking downward as the animal dives from the surface, to understand its aquatic use. Especially is its full width and steering power taxed to its limit as the beaver swims, tuglike, by the side of a pole or log which it is towing to the house, dam, or food cache, with only the tail thrown out sideways to keep from progressing in circles. On land the tail has other uses, but in the water it serves variously as rudder, propeller, and signal gun, by giving loud slaps on the surface of the water for warnings to friends or enemies.

In diving, beavers simply swim downward or in any direction under water. They swim long distances and remain submerged commonly for four or five minutes at a time, but much longer if alarmed, swimming half a mile or more without appearing at the surface. In winter, under heavy ice and mainly under water, they move about from the house or bank den to the food cache or feeding grounds on the bottoms or banks of the ponds or streams, getting air from the bubbles under the ice, from air-filled chambers, or through air holes kept open to the surface.

WALKING.

On land the beavers walk with a slow, heavy, shuffling gait, the tail dragging on the ground or being held slightly above and swaying from side to side. At times one will gallop along fast enough to keep up with a person at a slow walk, but the young soon get tired and out of breath. If frightened, they will make a rush for cover or for the water, but at their best speed even an adult can be easily outrun by a person. They seem to realize their limitations on land, and rarely are their cuttings or any signs of them seen more than a few rods from the water. Trees have been found cut as far back as 10 or 12 rods from the shore, but track, trail, or trace of beavers is rarely if ever found farther from water.

TREE CUTTING.

In cutting trees each beaver works independently, although several sometimes have worked on the same tree. A small tree is generally cut through from one side, but a larger tree is usually cut on two sides or all around. The chips are cut above and below and split out much as by a woodman's ax, and a large pile usually surrounds the base of a recently cut stump. The tree falls the way it happens to lean, but along the shore most trees lean toward the water. The bark is generally eaten from the chips as they are cut out of trees, poles, or branches before the chips are dropped on the ground. One old beaver will fell a poplar tree 3 or 4 inches in diameter, cut it into sections of 4 to 8 feet each, and drag it to the water in one night. A larger tree will often withstand the attacks of several nights and when down will provide work for the whole family or colony for a week or more in cutting, trimming, and carrying the sections of branches and upper trunk to the water. Trunks over 5 inches in diameter are rarely cut up or moved from where they fall, unless lying in the water or very near by. Trees a foot in diameter are often cut down, and occasionally trees as large as 1½ or 2 feet in diameter. The largest I have even seen cut was a balsam poplar in Montana, 46 inches across the stump.[1]

Tree cutting for food.—Poplars (Pl. II, Fig. 2) and cottonwoods, all species of the genus *Populus*, are the favorite food of beavers, and few other trees are cut where these are to be had. Willows, birches (Pl. III, Fig. 1), pin cherry, alders, and the bush maples[2] come next. Many small bushes, hazel, witchhopple, cornel, service berry, and raspberry are cut for food, and under stress of necessity such hardwoods as birch, maple, ash, cherry, and even oak are felled both for food and

[1] Photograph published in Wild Animals of Glacier National Park, National Park Service, U. S. Dept. Interior, p. 66, 1918.

[2] *Acer pennsylvanicum* and *A. spicatum.*

for building material. Such conifers as hemlock, spruce, balsam, and tamarack are rarely cut, and then only for building purposes, not for food. Pines are practically immune from the attack of beavers, although I have seen a photograph of one yellow pine that had been cut down by them.

DIGGING.

Beavers do a great deal of digging, mainly under water. Their ponds are usually considerably deepened by the removal of mud and earth dug up from the bottom and added to the dams and houses. Large burrows begun at the bottom of their ponds, lakes, or streams lead obliquely back into the banks and end in nest cavities above the water level, entered only from under water. These bank burrows are sometimes 40 or 50 feet long and large enough for a man to crawl into.

Extensive canals, or waterways, for floating timber and for swimming through marshes or lowland to a food supply are dug and kept open while in use. These are often 2 feet wide and 1 or 2 feet deep, while old, long-used canals are even deeper and wider. (Pl. III, Fig. 2.) Beavers rarely dig on the surface of the ground and never make a burrow with an exposed entrance; only under stress of confinement or alarm will they even scratch at the bottom of a wire fence when inclosed. I have kept an old one for three days on a lawn under an inverted box and have had good-sized young for a month at a time in a wire-fence inclosure with the bottom wire resting on the surface of the ground.

TRANSPORTING MATERIALS.

The carrying done by the beavers is one of the most surprising parts of their remarkable work. In transporting wood on land they grasp or hold it with their strong incisor teeth, and with heads turned to one side drag heavy poles or good-sized branches. A stick or small branch is carried in the mouth clear of the ground or partly carried and partly dragged. In the water a pole or small log is usually towed by the side, the teeth being fastened into the bark near the front end. At other times the log is grasped by the arms and front claws, while the beaver swims powerfully at the side and steers with his broad tail.

In carrying stones, of which the dams are sometimes largely built, the hands and arms are used, but as the stones are brought up from the bottom of the pond and carried under water the water displaced serves to reduce the weight actually lifted. Stones 5 or 6 inches in diameter are commonly used.

In carrying mud and small sticks from the bottom of the pond to be placed on the dam or house the beaver does not use its tail, but its

hands and arms. One will come up from the water carrying a huge armful, held tightly against its breast, and, rising on its strong hind legs, balanced by the tail pressed on the ground behind it, walk in an upright position to the top of the house and deposit its load. (See Plate I, Frontispiece.) As the slanting sides of the house are often a network of loose sticks, the strength and energy required of a beaver in climbing in the erect position and carrying a heavy armful is amazing.

CONSTRUCTING DAMS.

In building dams beavers work from the upstream side. Sticks, leaves, grass, sods, and mud are laid across the stream and are added to until the flow is checked and the water begins to rise. Then, as it rises, sticks are pushed over the top and allowed to lie crisscross on the lower slope (Pl. IV, Fig. 1), bound in and securely held by mud and earth added to the top and upper slope, until high and strong enough to hold the water of the pond at the desired level and to be impervious to leaks and withstand the pressure of floods. The ends are extended as the water rises, and the final form and position of the dams are often the result of long tests of strength and endurance, experiments, failures, and changes; some of the larger dams are the work of many generations of beavers, and even where the builders were destroyed a century ago the dams still remain like solid breastworks below the old beaver meadows.

BUILDING HOUSES.

Beaver houses (Pl. IV, Fig. 2) are sometimes started around a burrow leading from deep water up through the edge of a marsh or the bank of a stream or pond; sometimes they rise from the bottom of the pond in open water 5 or 6 feet deep, sticks and mud being piled up until the surface is reached, when the structure is continued upward until a living room can be inclosed above the water level. A new house is very simple and not very tight, but before winter begins the walls must be thick and strong, if it is to be used for living quarters. Sticks, usually first peeled for food, are laid crisscross in all directions and weighted down with mud, sods, plant roots, and the wet material dug up from the bottom and banks of the pond.

A well-built house is a dense and well-fortified structure with walls often 2 or 3 feet thick, of heavily reinforced construction. When well frozen the walls are hard and impenetrable even to the bear and the wolverene, credited with being old-time enemies of the beaver. A well-built house usually extends 5 or 6 feet above the surface of the water and often as much below, and may be 20 or 30 feet wide at the water level. Anything larger is unusual, but I have seen some which I estimated to be 7 feet high and 40 feet wide.

B23391

FIG. 1.—BEAVER DAM.

View from downstream, showing how sticks are pushed over the top to lie crisscross on the lower slope.

B23415

FIG. 2.—BEAVER POND, HOUSE, AND WINTER FOOD CACHE.

This pond in the Adirondacks extends under and along both sides of the railroad tracks and at its present level is harmless. If raised a foot higher the roadbed would be endangered.

B23892

FIG. 1.—TIMBER KILLED BY BEAVERS.

Part of a large area of spruce, tamarack, and white pine killed by flooding. The water was raised about 2 feet and the ensuing loss of timber was estimated at between $5,000 and $6,000. Most of this loss could have been prevented by lowering the water at the dam 1 to 2 feet, as illustrated in text Figure 2 (p. 11), and at an expenditure for labor and materials of not more than $25.

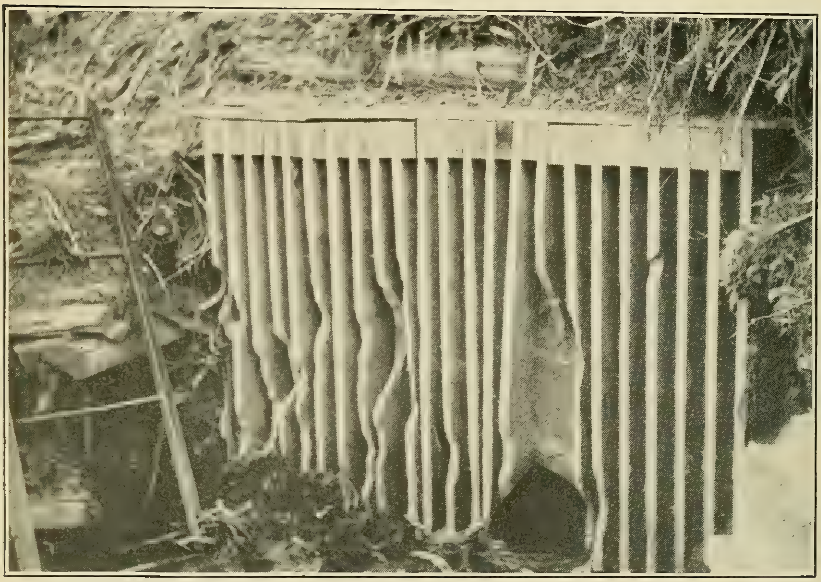

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FIG. 2.—RAILROAD CULVERT SCREEN CUT BY BEAVERS.

This culvert was repeatedly closed by the beavers and the water raised above the railroad. About a ton of sticks and mud had been taken out, and an iron ladder was kept there for use of the section crew, who removed the débris every few days.

The inner chamber is a simple cavity about 3 to 5 feet wide and $1\frac{1}{2}$ to 3 feet high. It is partly cut out and shaped from the inside, all sticks being cut off flush with the surface on the inner wall, and if more room is needed the chamber is enlarged from within. A semidry bed of grass, twigs, leaves, or shredded wood is made 2 or 3 inches above the water level and close to the water hole. One and occasionally two large holes in the floor enter the water and come out under the bottom edges of the house 15 to 40 feet away, forming safe means of entrance and exit to and from the living room. If alarmed in the house the beavers dive into the water hole and may not show themselves at the surface within a quarter or half mile of the house, but usually a line of air bubbles escaping from their fur shows their course as they leave the vicinity of the house.

BREEDING.

Beavers apparently begin breeding when 1 year old, as one or two embryos are often found in females of 25 or 30 pounds, but some may not breed the first year. At 2 years old, when weighing 40 or 45 pounds, they may have 4 young and this seems to be the normal number for most beavers. There are a few records of 6 young and two or three of 8 embryos found in large, old females; but as the females have only two teats on each of the two large mammary glands, more than 4 young must be abnormal. So far as we can tell, the sexes are about evenly divided in numbers.

The young are born in May and a few late litters apparently in June. There seems to be no evidence of more than one litter in a season, and there is no more than time for one litter to grow up and get ready for winter between May and November. The time of mating and the period of gestation are not definitely known.

The mother beaver takes good care of the young and brings them tender plants and rootlets before they are old enough to leave the house. The father apparently remains away while the young are small, but in a large house in August I found 2 females, 1 male, and 6 good-sized young. Like all rodents, beavers are polygamous, and the fact that fights among the males take place indicates that the older ones strive for supremacy.

DAMAGE BY BEAVERS.

The trees cut by beavers for food[3] and building material are generally of little value, mainly aspens, cottonwoods, birches, and pin cherries, or such shrubby woods as willows, alders, bush maples, hazels, and smaller bushes. However, some choice trees are occasionally cut along lake or stream fronts, or in orchards situated

[3] For food habits, see pp. 6–7.

near the water, and complaints are at times registered of real damage and losses; but in many cases the trees could be protected with strips of woven wire at a cost of a few cents each and the beavers left unmolested.

The most serious damage which the beavers occasion by their dams results from the raising of water levels in streams, ponds, or lakes, which flood the low ground and kill great areas of valuable forest trees. In places in the Adirondacks hundreds of acres of valuable white pine, cedar, spruce, balsam, hemlock, and tamarack have been killed by one beaver dam, inflicting losses of many thousands of dollars on the landowners.

In places beavers have increased to such numbers that their activities menace timber and other valuable property and make it necessary locally to control or destroy them. In most cases their control is not difficult.

Beavers sometimes dam the outlet of a lake and by raising the water level a foot or two kill all the trees around the shores, leaving a wide border of dead and dying timber that transforms beautiful and valuable camp or cottage sites or summer resorts into desolate, worthless wastes. (Pl. V, Fig. 1.) In a region which is popular and where camp and cottage sites are valued at several hundred or several thousand dollars each, the borders of a lake are often almost as valuable as city property, and such losses to landowners may reach a startling figure.

Other property losses are rarely so great, but are often very annoying. The flooding of roads and trails sometimes interferes with or suspends travel, delays lumbering or other business operations, or makes necessary tiresome detours and expensive repairs.

The flooding of railroad grades which cross low ground is sometimes serious, and has been known to interfere with the running of trains. Railroad culverts are frequently filled up by beavers in order that they may take advantage of the grades for their dams, and section crews are kept busy clearing out sticks and mud to keep the stream channels open. (Pl. V, Fig. 2.) There is sometimes actual danger to human life where the road bed is softened by high water and the track rendered unstable. Exercising those rare traits of animal intelligence, thrift, and industry which make beavers unique among our native mammals and of fascinating interest to

nature lovers brings them into disrepute when these activities run counter to the economy of civilization, and in such cases the animals are mercilessly denounced and many are killed. Ineffective methods of preventing their mischief cause much waste of time and unnecessary expense and only add to the unfavorable local sentiment against them.

BEAVER CONTROL.

Damage by beavers can be prevented by proper methods of control, based on a knowledge of the habits of the animals. Before any area is stocked with them the character of the country should be studied and suitable areas mapped, the beavers being restricted to these areas and trapping being allowed outside where the animals

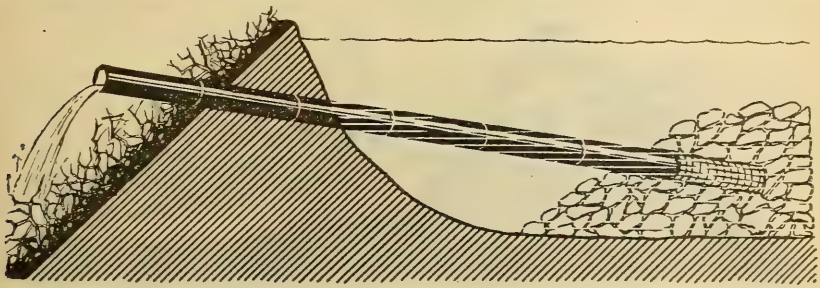


FIG. 2.—Pipe for lowering water in beaver pond. A 4 to 7 inch iron pipe with a cylinder of heavy wire mesh, inserted in the upstream end for a strainer, makes an effective drain for a beaver pond where it is necessary to lower the water only a foot or two. Larger pipes may be used or several small pipes laid together to carry a greater flow of water. Temporarily stovepipe can be used for such drainage.

would naturally do damage. It is useless to expect that beavers will remain and thrive where there is no suitable food or water, or in deep streams and lakes with high or rocky shores, or that they can be permitted to carry on their operations among small and closely cultivated farms, where they are sure to destroy property.

REGULATING THE WATER LEVEL OF BEAVER PONDS.

It is useless to tear out or dynamite beaver dams, as the beavers, if active, will replace them almost as fast as destroyed. A simple method of lowering the water and keeping it at any desired level above the beaver dam by means of a drainage pipe has proved, so far as tested, entirely successful. Many attempts have failed through imperfect methods, as the beavers will stop up the pipes or pull them out if possible, displaying much intelligence and energy in checking the water flow. The pipes must be securely laid and fastened down, with the intake thoroughly protected.

One or several pipes of sufficient size to carry the normal water flow should be laid through the dam with the outlet at the level at

which the water is to be held, the other end terminating in a wire strainer, reaching down into deep water and covered with stones or logs (Fig. 2). When the water has been lowered to the desired level the intake end of the pipe must still be well under water so that no marked current or water draft is perceptible at the surface. The pipes must also be securely held in place, so that they can not be pulled up, and the outlets must project a few feet beyond the lower face of the dam, in order that they may not be covered with mud.

In some cases it will be necessary to pipe the water some distance below the dam to prevent the beavers from building a second dam for retaining the water lost from the first. If the water is to be lowered to its original level a more elaborate system of drainage may be necessary, but in many cases lowering it 1 or 2 feet will save the timber

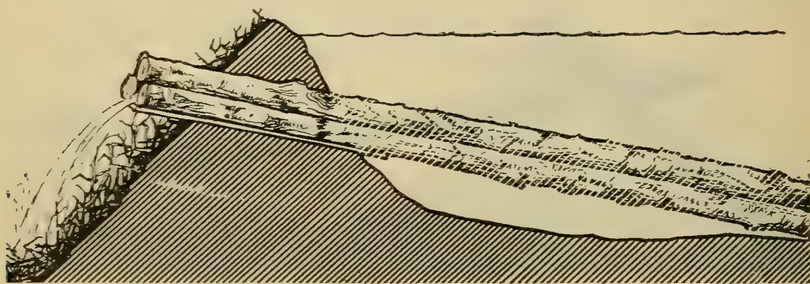


FIG. 3.—Three logs laid on a board or piece of sheet iron through the dam and sloping back into the pond, or more logs laid together to carry a greater water flow, in many places can be used to advantage to lower the level of the pond, in the same manner as that illustrated in Figure 2.

around the shores and still leave ample depth for the use of the beavers.

A very simple drain made of three or more straight hardwood logs laid on a board or a piece of sheet iron through the dam would serve in many cases as well as a pipe. The logs should be laid in the same manner as the pipe, two of them being slightly apart at the bottom and a third laid on top of them, their upper ends extending down into deep water (Fig. 3).

To discourage beavers from damming a stream, a blind drain of stones, logs, or tiling could be used, so that when a dam is started the water will still flow underneath.

FENCING BEAVERS.

One of the simplest and most important means of beaver control is fencing. While it may not be possible greatly to restrict the freedom of the animals on large streams or lakes, it is a simple matter to fence them on small streams or in lakes with small tributary streams. Advantage may be taken of their habit of not voluntarily

walking many rods back from the water, and of the fact that they will explore every possible stream and waterway, no matter how small, and even follow the bed of a tiny streamlet when dry in places in quest of new waters and a fresh food supply.

If a fence is constructed across small streams and out 15 or 20 rods on each side, the beavers will probably not go beyond it, although as yet this method has not been fully tested. By placing fences across strategic points in streams and valley bottoms, such as between high ridges or impassable banks, it will be possible in many cases to restrict the animals to certain areas, sometimes to a single drainage system or to a lake basin, so that generally, on large areas involving a complete stream system, fencing beavers should be far less expensive than fencing dry-land stock. On small areas of private property, however, it will usually be well to have the whole

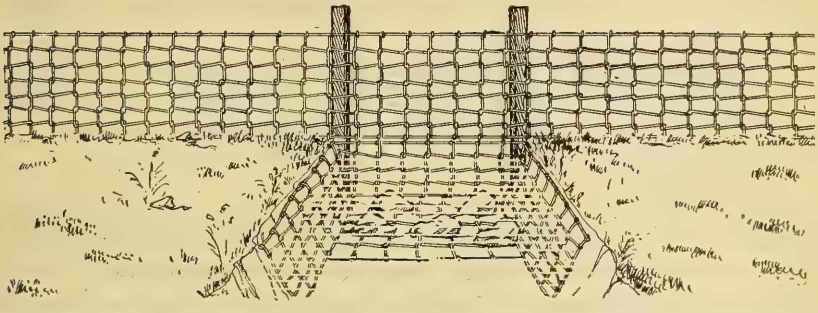


FIG. 4.—Beaver fence across creek. A beaver fence across a small stream should extend out 15 or 20 rods on each side and be securely laid on the bottom and along the sides of the banks of the stream. If desired, a passage-way or swing door in the bottom of the fence under water can be arranged to allow the beavers to pass in but not out of the inclosure.

area inclosed, and in some cases even to inclose the beavers with a fence which is proof against both dogs and men.

Types of beaver fence.—Ordinary poultry netting of 1-inch mesh will hold young beavers perfectly, but old beavers will cut it with their teeth and go through. The small young will climb up 2 or 3 feet on the inside of the wire and fall back; on one occasion a young one was known to climb to the top of a vertical 4-foot fence and tumble down outside.

To hold both young and old beavers, a 2-inch mesh fence of wires not smaller than No. 16 should be used. It should be 4 feet high, the top having a 6-inch overhang on the inside and the bottom being sunk 2 inches below the surface of the ground. I have never known an old beaver to climb over a fence or to dig under it unless there was a visible opening beneath it. Many of the woven-wire stock-fences would hold beavers perfectly, and if 5 feet high no overhang would be required.

Below the surface of the water, however, beavers will dig under or around a wire fence unless laid on the bottom or extended into the banks of the stream. It is necessary to use another width of fencing under water, laid out flat on the bottom and weighted down with stones or fastened with stakes, and to stretch securely staked side wings along the banks for several feet. (Fig. 4.) If the fence is to prevent the beavers passing either way the bottom and side wings should be used on both sides of the fence. If the beavers are to be permitted to pass in and not out of the inclosure, a V-shaped or funnel-formed opening or swinging door should be placed in the fence near the bottom.

The wings of the beaver fence should stand at right angles to the stream or converge to an apex at the banks, the ends being curved inward toward the stream to serve as an additional check. They should extend in most cases 15 or 20 rods beyond the flood and high-water points.

In times of flood or high water it will be necessary to guard against driftwood clogging the fence and possibly to build a secondary span of fence across the stream channel above to catch it.

TRAPPING FOR FUR.

In most parts of the country beavers are kept down to meager numbers by trapping, either legally or illegally, and in any section where they are doing damage they can be promptly removed by providing an open season for taking them. In fact, they are so easily trapped as to be one of the most difficult animals to protect. Except in large rivers and lakes, it is usually possible for experienced trappers to get all of them.

Trapping beavers for fur as practiced by amateurs is generally inefficient. Unless scarce and very shy, beavers are as easily caught as muskrats, but if the traps are not properly set and placed they will be found to contain only feet, the animal thus suffering needlessly and being lost to the trapper. If caught by a hind foot a beaver will sometimes still be found in the trap in the morning, but if caught by a front foot the leg bones are quickly broken and the foot twisted and torn off.

Weighted steel traps.—To obtain best results a double-spring No. 3 trap should be used with a stone weighing not less than 20 pounds securely wired to the bottom or outer spring. (Fig. 5.) The trap should be set 6 or 8 inches below the surface of the water where the beaver lands at the shore, or on the dam, and always near a depth of at least 2 or 3 feet of water. A 15 or 20 foot wire attached at one end to the trap chain and at the other to a strong stake driven below the surface of the water will allow the beaver to drag the trap and stone into deep water, from which it can not rise to the surface for air, and in a few minutes, probably not over 20 at most,

it will be drowned.[4] As trap and beaver are well hidden under the water, other beavers are not frightened away, the fur is uninjured, and there is no danger of the carcass being torn or eaten by predatory animals. It is the simplest, safest, and most merciful method thus far devised for taking beavers in steel traps.

Trap and slide pole.—Most trappers use a slide pole for fastening the trap and drowning the beaver—a long slender pole being thrust through the ring of the trap chain or a wire loop and slanted out into deep water and firmly bedded in the bottom. If properly arranged and slanted and in sufficient depth of water, the slide pole will act eventually to drown the beaver. Sometimes a wire or long chain is used instead of a pole, but this method is generally more difficult and less satisfactory than using the weighted trap.

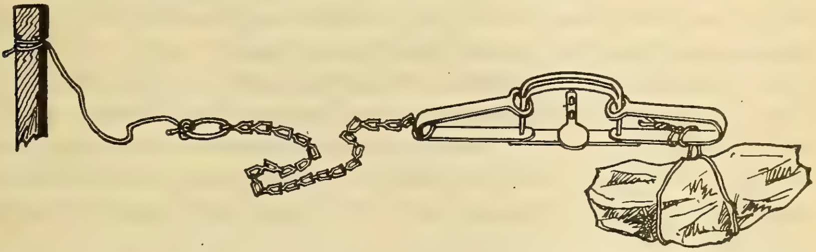


FIG. 5.—Weighted trap for drowning beaver. A stone weighing 20 to 30 pounds securely wired to the outer spring of the trap will sink and drown the beaver in a few minutes after it is caught if the trap is set where the animal can reach deep water.

Other methods.—Success in trapping depends largely on a knowledge of beaver habits. The animals will be driven away if the houses and bank dens are disturbed. Steel traps should not be set in water not deep enough to drown beavers. Other methods of trapping are mentioned in connection with capturing the animals alive for fur-farming purposes (p. 18).

PUBLIC AND PRIVATE TRAPPING.

Under the present system of game laws it is very difficult to protect beavers from illegal trapping, even on public lands and in public parks, and a radical change in sentiment toward the animals is desirable if they are to become valuable as public or private property. If beavers can not be kept under control by regulating water levels above their dams, or by fencing, trapping in season for fur, or by trapping alive and transplanting (see p. 23), they can always be checked and their ravages ended by allowing them to be trapped on private lands with the permission and under the direction of the landowner. This would stop all complaints and meet all objections to the introduction of beavers and would also encourage beaver farming.

[4] U. S. Deputy Game Warden Willett T. Gray, of Ashland, Wis., tells me that he has frequently timed trapped beavers that stayed under water for 15 minutes; in one case 17 minutes elapsed before an animal was forced to come to the surface for air.

Eventually, when public lands are sufficiently stocked, a limited amount of trapping on them should be allowed, preferably by public employees under rigid rules and inspection. The beavers should be taken alive and selected for fur and only the darkest and best left for breeding stock. In many cases the National and State forests, if fully stocked with the best beavers, should yield a valuable annual crop of high-grade fur.

NATURAL ENEMIES AND CHECKS.

Natural enemies of beavers have been bears, wolves, mountain lions, wolverenes, and probably coyotes and bobcats. Whether otters enter the houses and kill the young beavers has not been satisfactorily determined, but there is reason for believing they do. Dogs are likely to prove a serious menace if beaver farming becomes established in settled regions. Large snapping turtles might easily kill young beavers and should be exterminated from beaver ponds.

Diseases seem to be unknown among beavers in a wild state, but in zoological parks the animals have been known to die of tuberculosis, and it would seem a wise precaution to keep their surroundings in a sanitary condition. They are singularly free from insect parasites and their life in cold water seems to keep them in a generally healthy condition.

BEAVER FARMING.

That beavers are easily domesticated has been amply demonstrated, but raising them in captivity has not been carried far enough to gain all of the knowledge necessary for raising them successfully on a business basis. Under the very unfavorable conditions affecting animals on exhibition in zoological parks many litters of young beavers have been raised, notably in the Bronx Park at New York and in the National Zoological Park at Washington, so that the question whether they can be bred in captivity has already been determined.

> Raising beavers for their fur under complete control or under semidomestication has not been thoroughly tested, but from a careful study of the habits and requirements of these interesting animals beaver farming in proper localities promises success if rightly managed. A beginning should be made with the darkest, handsomest, and most valuable stock and then the principles of selective breeding should be observed.

Young beavers are easily tamed and probably are the best stock to start with, but even adults have become thoroughly tamed and sufficiently gentle to be handled by those accustomed to animals. With plenty of clean water, good sleeping quarters, and a suitable food supply they can be kept in either large or small areas, and there seems no reason why they should not thrive and multiply in a satisfactory manner.

VALUE OF FUR.

The first question in regard to raising any animal for fur is whether the price its pelt will bring will be sufficient to pay the cost of raising and to yield a profit. Beaver fur has been generally considered low priced, and some of it is, but few animals vary more widely in value according to geographic areas. Skins from the lower Colorado River and Rio Grande are the palest, lightest furred, and lowest priced, the lowest recent quotations being \$6 to \$8 each, while the heavy-furred, dark-brown skins from Canada and Alaska in 1921 brought \$20 to \$25, and rare "black beavers" were quoted as high as \$38. In northern Wisconsin choice skins have recently sold as high as \$50 each. Obviously, if beaver farming is to be a success, only the choicest stock should be selected to start with, and this should be improved by selective breeding until the most beautiful fur of the highest grade and highest price is obtained. That \$50 beaver skins can be produced in captivity seems probable, as in recent years the best beaver fur has not been legitimately in the market. Were actual values of beauty, warmth, and wear considered, choice black beaver should bring a much higher price. Under such conditions a reasonable profit would be assured.

SELECTING A LOCATION.

The longest, heaviest fur is produced in cold climates and the best beaver country is found in the Canadian and Hudsonian Zones, regions usually of relatively little agricultural value. In the United States these zones cover parts of the northern tier of States and extend farther south in parts of the colder mountain regions. The range of the aspen or poplar tree [5] is a good index to suitable beaver climate and conditions. (See map, Fig. 1, p. 3.) The aspen also furnishes the best beaver food and at present has relatively little commercial value. It grows naturally across the northern part of the continent from the barren grounds of Canada and Alaska south to the northern parts of the United States and, in the mountains, to northern Mexico. Wherever this tree is found, if other conditions are favorable, beaver farming might be successful.

Much of the best beaver country is in localities where, after the original timber has been lumbered off and the ground burned over,

[5] *Populus tremuloides* and varieties.

thickets of aspen and pin cherry have sprung up as second growth. Such land is generally considered almost worthless, but it might support a large beaver population and could be successfully handled on either a large or a small scale. A small fur farm, where detailed attention can be given to the animals, is likely to prove most successful at first and it can be extended when management practices are fully mastered.

Should beaver farming on suitable areas prove a profitable enterprise, it would make remunerative considerable areas of now unproductive lands where such an industry would be valuable. The possibilities of success in beaver farming under proper conditions render this an attractive field for well-managed experiments.

A small natural pond or lake, or a small creek that could be fenced above and below to hold the beavers, would make a good site for a beaver farm, but if such sites are not to be had, a small artificial basin scraped out and filled with water from a spring, or even pumped from a well, would do for a beginning. The two essentials are water and food. A long section of stream valley, the headwaters basin of a stream system, or a lake or chain of lakes would afford ideal locations for extensive beaver farms.

FENCING FARMS.

After the location has been selected, an inclosure must be prepared that will hold the beavers and protect them from outside enemies. The specifications for fencing given under the heading Beaver Control (p. 11), will apply here equally well, but the more valuable the animals become the more difficult will it be to prevent losses from theft. In some localities only short sections of beaver-proof fencing will be required, but in others, a fence strong enough to exclude poachers and dogs will probably be necessary. Care and watchfulness will always be required, however, and the method of turning beavers loose to multiply without further effort or attention on the part of the owners will generally prove disappointing.

CAPTURING BEAVERS ALIVE.

Catching the young.—For domestication it is better to start with young beavers. They may be taken and raised at any time after

their eyes are open. Apparently they do not leave the house or bank den where born until a month or 6 weeks old, or some time in July. At that time they weigh 3 or 4 pounds and are easily caught in the water with a boat. They can be driven out of the house by shaking it or thrusting a slender stick into the nest cavity and rattling it around. In some places they can be scooped up in wire mesh dip nets as they come from the house through their under-water canals, but they are more likely to be first seen swimming with heads just above water not far from the house. In such cases, two people in a canoe, one in the stern to paddle and one in the bow to watch, can easily catch them. As they dive, the direction should be noted, the boat should be driven beyond the spot, and the water should be watched on all sides for the next appearance. Young beavers will not remain under water very long, rarely over two or three minutes, and after several swims under water they become tired and are readily approached and picked up by the tail as they come to the surface and pause for breath. They do not attempt to bite, and if carefully handled are gentle and quiet from the first.

It is usually possible to locate young beavers in a house by listening to their babylike cries, as they habitually cry a great deal, especially when hungry or disturbed. When old enough to come out regularly for food they can be seen before dark swimming about near their house or a little way out in the water. It is best not to disturb the houses unless young are known to be in them, but if great care is taken not to injure a house and to close securely any openings made, the young will not usually abandon it. If bank dens could be located, the young could probably be caught in them, but as there is no over-ground house to mark the spot and the under-water doorways are well hidden it is difficult to take them there.

Corral traps.—Both old and young beavers may be caught in corral traps at the edge of the water. A circular corral may be made of 2-inch woven-wire mesh, not lighter than No. 16 wire, at least 8 feet in diameter and 4 feet high, with a 3-foot door on the pond side. About seven posts or strong stakes will support the wire, which should be buried a few inches below the surface of the ground and at the top be bent in a 5-inch overhang on the inside. The door posts should be double if a drop door instead of a swinging door is used. Several kinds of swing doors can be devised, but the drop door is perhaps the simplest. It should be raised $2\frac{1}{2}$ feet and hung from the top by a light, easily sprung trigger, with a string attached to a piece of green aspen for bait in the back of the corral or with a long thread to be pulled from a distance when the beavers are inside. (Fig. 6.)

The beavers can be baited first in the water in front of the corral, then closer, and soon inside. When the whole family or colony have formed the habit of coming into the corral the door can be set and made ready for their capture.

In most places green aspen bushes or branches make the best bait and will soon bring the beavers regularly for their meals. If these are not available the favorite local food can be used and will be preferred by the beavers to that which is only to be had by going back from the shore and cutting.

Pitfalls.—Adult beavers may be caught in pitfalls sunk across the regular trails where they drag their wood to the water (Pl. VI, Fig. 1). A hole 14 inches wide by 2 feet long should be dug across the

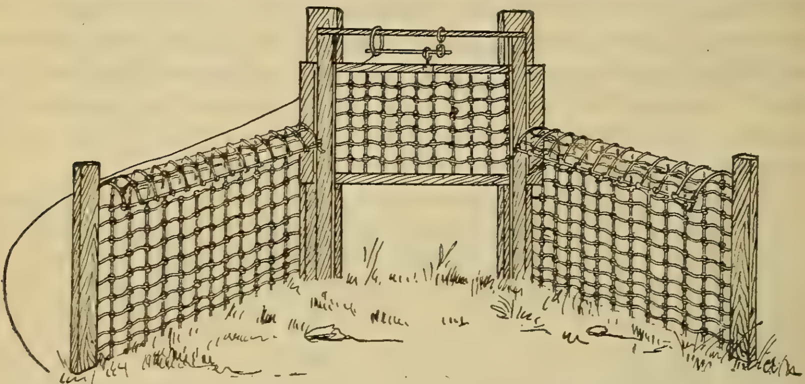
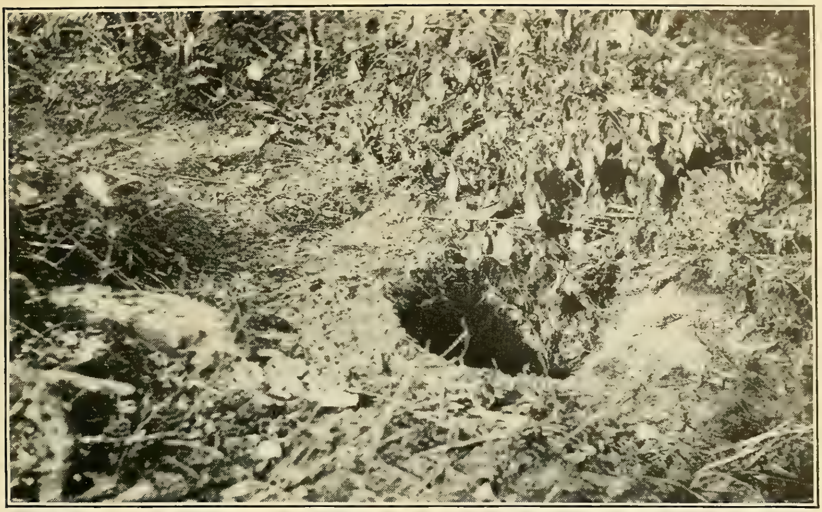


FIG. 6.—Corral for capturing beavers alive. Either drop, swing, or sliding doors can be arranged for closing the corral, but the drop door is the simplest where the beavers are to close it themselves from within. Three wire loops and a straight stick for a trigger provide a simple and effective means of springing the door.

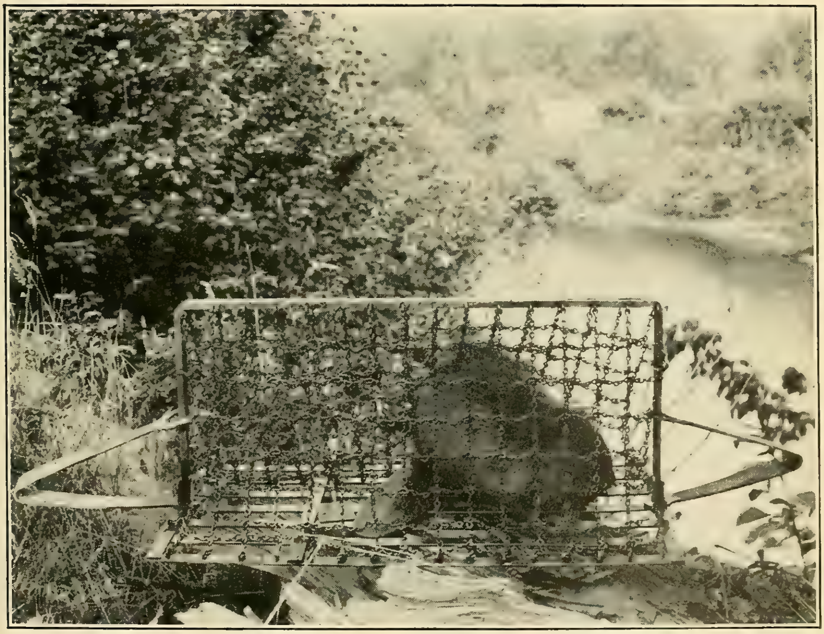
trail 6 or 7 feet deep and the excavation enlarged below to a diameter of 3 or 4 feet. If a barrel or tin can is available it might be sunk in the ground in the trail for holding the beaver. If the pit is in sandy or mellow ground the bottom and the sides up 2 or 3 feet must be protected with boards or tin to keep the beaver from digging into the walls and filling up the pit in order to climb out. The excavated earth from the pit should be carried away in pails or sacks and the surface of the ground left in as natural and undisturbed a condition as possible. When all is completed, the tops of bushes should be laid in from both sides of the trail to near the middle of the mouth of the pit and the remainder covered with slender sticks, over which leaves and grass are scattered so that the hole does not show. The beavers may tumble in on the way to their feeding grounds, but are more likely to do so on the return trip, when occupied with carrying or dragging sticks to the water. Once caught in the pit they are easily dipped up in a wire basket or inclosed in a large sack slipped over their heads and bodies.



B23416

FIG. 1.—PITFALL FOR CATCHING BEAVERS.

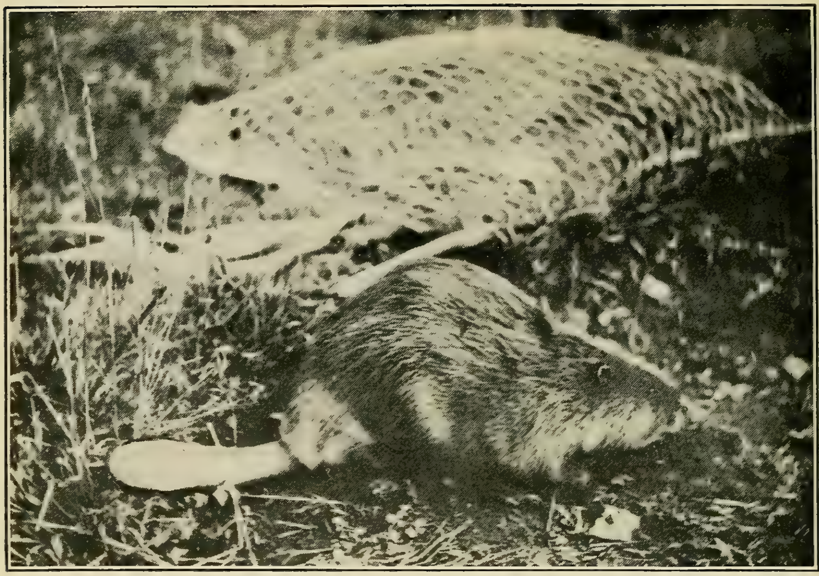
This should be dug across a beaver trail, 5 to 6 feet deep, and lined with boards or tin around the sides at the bottom to keep the beavers from digging out. Three beavers were caught in three successive nights in the pit illustrated.



B22759

FIG. 2.—HEAVY TRAP FOR CATCHING BEAVERS ALIVE IN WATER.

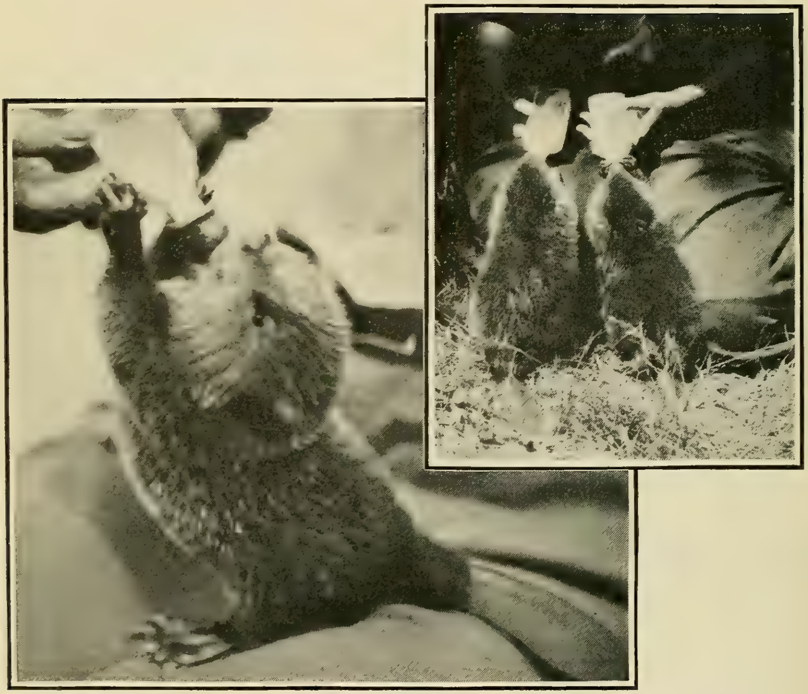
This was used with success by field assistants of the Biological Survey, but is too heavy and expensive for general use. Weight 45 pounds; cost about $50. A trap of similar type is illustrated in text Figure 7 (p. 21). (Photograph by T. H. Scheffer.)



B23384

FIG. 1.—WIRE-MESH CARRYING BAG AND RECENT OCCUPANT.

The bag is easily made of poultry netting laced at the top with wire. A slender pole thrust through the mesh makes it possible for two people to carry it on their shoulders.



B23401–B23405

FIG. 2.—"BOTTLE" BEAVERS GETTING THEIR BREAKFAST.

They are about 3 months old and weigh about 4 pounds each. The experiment with regular baby feeding bottles indicates the possibility of using more-natural foster "mothers," such as sheep or goats.

Steel traps.—The commonest method of capturing beavers alive is by use of No. 3 steel traps with the jaws well wrapped with cloth. The trap should be set under 8 inches of water just above a small break in the dam. The break need not be more than a foot wide and 2 or 3 inches below the water level, just enough to make a low roar that will be heard over the surface of the pond. One end of a piece of telephone wire, or similar wire, should be fastened to the trap chain and the other end to a bush or tall stake on which a cowbell is hung. The beaver will often come to repair the break before dark and may be caught and taken out of the trap early in the evening. It may sometimes be necessary for the trapper to sleep near the cowbell, as the beaver should be taken out of the trap before its

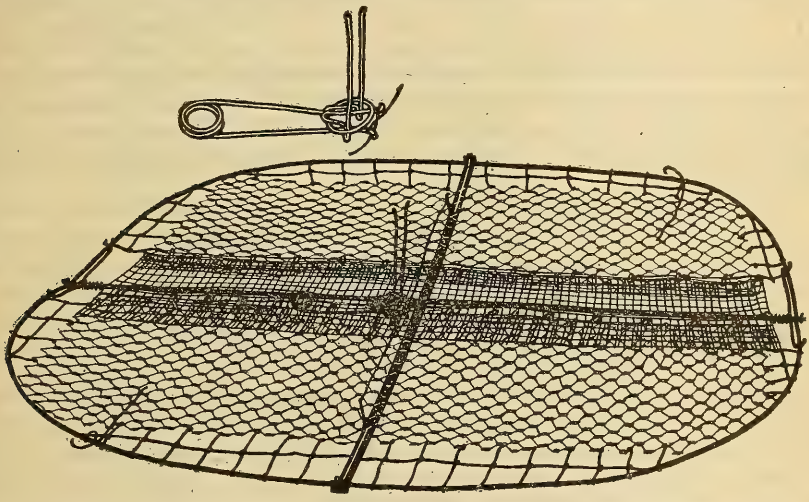


FIG. 7.—Light trap for catching beavers alive. This can be made at home or in any blacksmith shop at a cost for materials of about $5 or $6. Weight about 27 pounds.

foot is injured in struggling to escape. A wire basket should be at hand into which the beaver may be dropped before being released from the trap.

Cage traps.—A large trap on the general plan of a steel trap with wire or chain mesh sides to close over the beaver and catch it alive has been successfully used by the Canadian Park Service and by field assistants of the Biological Survey in the State of Washington (Pl. VI, Fig. 2). It is very effective in certain places where the animals pass through canals or along shallow streams, its main disadvantage being its bulk, weight, and cost.

A trap of somewhat different type seems preferable, especially for use in places where beavers pass along waterways. One can be made at home, or in a blacksmith shop, by any one of a mechanical turn, at a cost of $5 or $6 for materials. This trap when completed

weighs about 27 pounds. It may be constructed as follows (see Fig. 7):

Use two 5-foot strips of strap iron $1\frac{1}{4}$ inches wide by $\frac{1}{4}$ inch thick for base; two $\frac{3}{8}$-inch steel rods, 8 feet long, for jaws; two 4-foot sections and two 6-foot sections of $\frac{3}{16}$-inch steel spring wire (No. 6) for coil springs; and 10 feet of 1-inch or $1\frac{1}{2}$-inch mesh woven-wire poultry netting, 3 feet wide, of No. 16 wire, for the sides and bottom. For tools, a $\frac{3}{8}$-inch drill, heavy pliers, hammer, wrench, and wire shears are necessary.

In the longitudinal base section of strap iron a hole should be drilled in the middle and two side by side in each end, and in the cross section a hole in the middle and one in each end. The ends of the longitudinal and cross sections should be bent up at right angles, $1\frac{1}{2}$ inches above the base. These two strips should then be bolted together at right angles with a $\frac{3}{8}$-inch bolt through the middle holes. By loosening this bolt the crossbar can be swung around under the trap to make it narrow for carrying. Bend the two rods for the trap jaws into an approximate semicircle with upturned ends an inch long. Slip the ends into the two holes in each end of the longitudinal base strip, leaving enough spring in the jaws to hold them in place.

Make coil springs of the two 4-foot pieces of spring steel wire by winding the middle of each closely six times around a $1\frac{1}{2}$ inch pipe, and of the two 6-foot pieces, eight times around. This should be done while cold, or if heated, the wire must be very perfectly retempered. The straight ends of the wires can be heated and bent out $1\frac{1}{2}$ inches at right angles and these right-angle sections curved sideways to clasp the trap jaws, with the 4-foot springs about 7 inches above the base and the 6-foot springs about 12 inches above the base. One of the long coil springs and then one of the short ones should be slipped over each end of the longitudinal base strip before the jaws are inserted in the end holes (only one of each pair of springs is shown in the illustration). After the jaws are in place the two ends of the short spring should be crossed with a strong tension and clasped around the jaws up about 7 inches from the base, then the long ones above them. The coil springs are light and give a quick, strong action to the jaws. A double-ended jump-trap spring of strap steel between the jaws and bolted down in the middle would have some advantages, but would add to the weight of the trap.

The wire mesh should be put on in five sections, one a foot wide the whole length of the bottom of the trap and wired securely to the longitudinal section; one on each side wired all around to the jaws and hinged at the lower edge to a 5-inch strip, with its lower edge again hinged to the piece on the bottom, so as to fold in as the trap is opened. This leaves the sides slightly full and convex, giving the closed trap a clamshell form with plenty of room inside for the beaver. The side walls should not be too rigid, but can be given ample play by being loosely hinged to the jaws and bottom strips. Wire rings or **S** links may be used for hinging. Clasping hooks on the edges of the jaws to lock them when the trap is sprung render it possible to use these light-rod jaws instead of heavier material

The trigger for springing the trap must stand upright in the center and spring by a slight pressure from any side as the animal swims against it. This can be accomplished in many ways, but the form shown in the diagram works perfectly and is easily made. The jaws must be held down on both sides by heavy wire catches, which, to give light pressure at the tips, may be 10 inches long, the tips held down by wire loops around the bottom cross-bar and the other end hinged in the holes at the ends of the cross-bar. The loops can be released simultaneously from both sides by crossed wires attached to a small double spring in the center wired to the longitudinal strip; this is released by a touch from any side on the upright trigger.

The trap should be set in the middle of a beaver canal or narrow water channel or in a pond, 10 or 12 inches below the surface of the water, with the upright trigger about 1 inch below the surface, where the beaver will swim against it, or an aspen twig may be attached to the trigger as bait.

Beavers may be taken out of the trap by the tails and dropped into a wire-mesh carrying bag (Pl. VII, Fig. 1), or a large gunny sack may be slipped over their heads and bodies while in the trap and used as a carrying sack. A slender pole can be run through the wire basket or through loops at the ends of the gunny sack, so that two people can carry the beaver between them on their shoulders.

TRANSPORTING BEAVERS.

Beavers are easily handled, and surplus stock in one locality may be shipped for long distances if properly crated. Adults will rarely eat anything if kept in close confinement and should be shipped at once to their destination or else kept in an inclosure large enough to have a house and a swimming pond well supplied with food.

For two adult beavers a box 3 by 4 feet and 1½ feet high should be used, with partly open wire-mesh top and hand grips at the ends. One end or corner should be covered or inclosed for a dark retreat and nest. For food, bundles of aspen branches, or cottonwood, hazel, bush maple, or willow should be nailed to the sides and some branches, twigs, and leaves laid on the floor. For a three or four days' journey, two loaves of white bread should be fastened into the corners and a box containing 2 pounds of rolled oats nailed to the side or bottom of the box; a tin pan to hold a quart of water should be fastened in one corner, so that it can be filled from the top; no additional food need be supplied, but instructions should be given and written on the label, to keep the tin pan half full of water. Beavers are thirsty animals and suffer if they do not have plenty of water to drink. They show no inclination to gnaw out of the box when there is daylight above and will travel quietly and comfortably, except for fear and nervous excitement, which should so far as possible be avoided. The box should be marked *RUSH*, and no

delays allowed. At their destination the beavers should be placed at once in a pond or other swimming water and given a dark nest place. With this treatment their fear and nervousness will soon be removed and they will eat and function normally.

SELECTING BREEDING STOCK.

So far as is at present known, the darkest, richest-colored, and handsomest beaver fur is found native along the south shore of Lake Superior, in northern Michigan and Wisconsin.[7] In this region of heavy forest and deep snows the outer hairs of the animals are very dark brown and the underfur is almost black. When tanned and plucked the skins are very beautiful, and when made up into wearing apparel they almost equal sea otter in depth of fur and richness of color. They are decidedly superior to the Canadian and Alaskan skins, which have generally been considered the best and highest priced, but have only recently been quoted in the fur markets, as for many years the beavers of the region south of Lake Superior have been carefully protected and only taken illegally or for scientific specimens. They are now fairly abundant in this region, but an open season would greatly reduce their numbers. The disastrous effect of even a short open season where beavers have become tame has been demonstrated many times, and even the bungling methods of amateur trappers leave but a few crippled beavers to slowly restock the waters. If the beavers of the region south of Lake Superior are to be trapped it should certainly be as live animals for breeding stock. There are also occasional "black beavers" (melanistic individuals) throughout the north country, which always command high prices, and which may be utilized as breeding stock.

If a choice dark variety of beaver is bred successfully it would probably not be necessary to sell the skins for many years, as the demand for breeding stock should make the price for live animals much greater than their fur value. If a reasonably satisfactory maximum price could be established for live beavers the industry would thrive, but wildly speculative prices, such as black foxes have at times attained, would seriously handicap the enterprise. This danger is not imminent, however, as the source of supply is ample and there is no possibility of a cornered market for breeding stock.

There is always a distinct advantage in having fur raised under control, for superior prices can be obtained by marketing it when at its very prime, by selecting the animals at the right age and season and in the best condition for quality of fur. Relatively little

[7] The beaver inhabiting this area was described in 1913 as a new subspecies, the woods beaver (*Castor canadensis michiganensis*) from Tahquamenaw River, Mich. (Bailey, Vernon, Proc. Biol. Soc. Washington, vol. 26, p. 192, 1913).

perfectly prime wild fur is taken in the United States, even in the open season.

To improve the stock by selective breeding the choicest animals should be reserved for breeders and all inferior ones marketed for fur. For convenience in handling them, the corral traps (see p. 19) should be used. Suitable corrals or feeding yards can be kept in permanent use in order that the beavers may be inclosed at any time while feeding. The more accustomed they become to the presence and voices of people the less nervous and alarmed will they be when it is necessary to capture and handle them.

MARKING FOR SEX AND AGE.

The genital organs of beavers are internal, making it difficult to determine the sex. The male has a straight bone an inch to an inch and a half long in the penis, lying between the two large musk glands under the skin just in front of the anus. The female may be recognized by the absence of this character and by the two conspicuous teats on each of two mammary glands. The shape of tail and other external characters seem to have no relation to sex.

Every beaver should be carefully examined and in some conspicuous way marked for both sex and age. Branding on top of the tail with either a hot iron or chemicals would be permanent and conspicuous. Either recorded numbers or a sex mark and the year of birth might be used.

FEEDING AND CARE.

Young beavers can be raised on cow's milk and take eagerly to the nursing bottle (Pl. VII, Fig. 2). In the early fur-trade days they were occasionally nursed by the Indian women and raised as household pets. They could probably be nursed by such foster mothers as sheep, goats, and possibly dogs. Undiluted cow's milk is apparently too rich for them, so it should be skimmed or separated and boiled, and if it produces diarrhea should be given with lime water. When fresh milk can not be obtained powdered whole milk can be used. While little, beavers must be fed small quantities every four hours, night and day, to keep them quiet. If fed at longer intervals they are sure to overeat, with bad results. They should be encouraged to eat green vegetation and roots as early as possible. When about 2 months old they may be weaned and will live on green vegetation, leaves, twigs, and bark and roots, with rolled oats and bread as extras.

In fur farming one of the first considerations is an accessible supply of the proper food. There seems to be no overcrowding or overpopulation in beaver colonies where there is plenty available,

but after a few years, when the aspen and other choice foods are cut back for 8 or 10 rods from the shore, the tendency of beavers is to hunt for new quarters. When the supply becomes low on beaver farms, aspens or other desirable trees or bushes, when cut and hauled to the shores, provide an ample supply of food for summer and winter at little expense. By occasionally burning cut-over areas at the proper season a new supply of aspen would spring up. From information available it appears reasonable to estimate that a section (640 acres) of good aspen land ought to feed 1,000 beavers indefinitely if well managed.

Many other trees, bushes, and plants (see p. 6, under Tree Cutting for Food) are eaten by beavers and should be included in their food for the sake of variety. Coarse water grasses, rushes, sedges, and cat-tails are extensively eaten in summer, and waterlily rootlets, stems, and leaves are a choice food. Clover and alfalfa are eagerly eaten and could be raised on the slopes near the water as a supplemental food supply. Young beavers are especially fond of red-clover heads, lily-pads, and cowslips, and of the leaves and twigs of aspen, hazel, pin cherry, willow, mountain maple, striped maple, and various birches. As they grow older they eat more bark, and in winter their main food consists of bark, leaves, and twigs from the wood cached under water. Some roots and green vegetation may also be found along the shores and on the bottoms in winter. Both young and old beavers are fond of bread, rolled oats, and cracked corn, and possibly of other grains also. The effect of a variety of foods on the size and vigor of animals and on the color and quality of fur is a problem for future study.

Artificial houses should be provided where a new colony is started. A plank or log house 4 feet square with a hole in the bottom and a door in the back may be set over the edge of the pond with the bottom just touching the surface of the water, so the beavers can come up inside. A metal trap door opened and closed with an iron rod from the outside can be fitted over the water hole, so that the beavers can be shut in and examined at any time. If kept in this house overnight or a day before being released they will come back to it and use it regularly.

Under normal conditions beavers never deposit their feces except in the water, where they sink to the bottom or dissolve and disintegrate. I have never been able to find a trace of them in the houses, not even in those occupied by young, nor on the banks or shores. In captivity the beavers often hold their pellets as long as possible if no water is at hand, and unload them as soon as they get into water again. For this reason they should always have access to clean or running water.

HARVESTING THE CROP.

TAKING AND PREPARING SKINS.

Beaver skins should be taken only in midwinter, when the fur is prime, unless there should be a special demand for unplucked beaver fur, which is at its best before the outer guard hairs are full grown, while short and very glossy in September. It is then much like unplucked otter fur, and especially suitable for men's coats or collars.

The skins are usually taken off by a cut along the median line of the belly and stretched in circular form on a board or hoop. They must be carefully removed with a very sharp knife, as they do not peel off, but have to be cut close to the skin all the way. The skins should be stretched and dried in a cool dry place and kept cool until marketed, so that the oil will not soften and injure the leather.

UTILIZING THE MEAT.

After being skinned and dressed a beaver will weigh about half as much as before, that is, a fair-sized animal will dress about 25 pounds. This should include the tail and liver, which are especial delicacies. The tail is fatty tissue, very rich and palatable when cooked, and greatly relished by early trappers and explorers. The liver is large and almost as tender and sweet as that of a chicken or goose. The body meat has rather a gamy flavor, but if properly cared for and cooked is excellent and was generally preferred by trappers to any other game, even in the early days when buffalo, elk, and deer were abundant.

Great care must be taken in skinning a beaver not to get a trace of the musk on the meat, or it will be ruined. The musk and oil glands should be left on the skin until after it is removed, and especial care must be taken not to get any musk on the knife or hands. The musk glands have a commercial value. The carcass should be hung up by the head and kept clean. It might be possible to develop a good market for beaver meat if properly handled.

CONCLUSIONS.

Importance of beavers.—Beavers are of primary importance as fur bearers and conservators of water and soil; because of their unique habits they are also animals of general interest. In certain types of forest country, on farms, in irrigation ditches, and along trails, roads, and railroads, they are capable of doing serious damage; in such situations it becomes necessary either to remove them or to control them intelligently. Their control, however, is not difficult, and where they are doing damage on private lands they can

be quickly removed either by trapping alive for shipment or in the ordinary way for their fur.

Attitude toward beavers.—If beavers are to be treated as public property, it is as objectionable to place them on private land where they will destroy crops and timber as it would be to turn herds of hogs and cattle into cultivated grain fields to fatten on what they like best. A thorough knowledge of their nature and habits is necessary for their control, as also for their successful culture. In many States the game laws provide for a license, allowing the capture and raising of fur-bearing animals under necessary restrictions as a private industry, and in other States where there is no such provision the legislatures might well authorize the game commissions to provide such licenses and to take such other means as are necessary fully to control and regulate the beaver industry and protect private property.

Beaver farming.—The practicability of beaver farming has not been fully demonstrated, but from present knowledge it seems reasonable that the business of raising beavers for their fur will develop into a profitable branch of fur farming. Many problems must later be worked out, such as family and sex relations, extent of sociability and enmity, effects of large numbers on the health and increase of the stock, possible diseases, protection from natural enemies and poachers, and actual values and proper prices. However, the more immediate problems of capture, feeding, breeding, fencing, control, and shipping have been partially solved. To start beaver farming on a large scale at present would probably be unwise, but with a small beginning the enterprise seems to promise good returns and even great possibilities. When fully established it should greatly increase the value of a large area of north country and, by insuring a permanent supply of excellent fur, open up a new industry where greatly needed. Only such areas as are determined to be suitable should be stocked with beavers; the animals should not be introduced uncontrolled into places where their activities may menace irrigation or power ditches or important road or railroad grades. Sites selected for them should contain a suitable food supply and permanent water.

Utilizing forest areas.—Over a large part of our millions of acres of national forests beavers are capable of far more good than harm in conserving water and soil, weeding out timber of little value, making the silent places teem with interest, and yielding substantial returns in an annual fur harvest. With intelligent control to avoid local damage to valuable timber and other property and with wise restraint to prevent the dispersal of beavers over surrounding country, the usual complaints of damage can be eliminated. On some of the national forests beavers are already present and in places in-

creasing in numbers, but most of the animals are the western, pale, native varieties, worth much less than the choice, dark, prime fur bearers which might be introduced from other sections. Improving the system of stocking, management, and control will place beavers among our valuable forest products.

Cleared timberlands.—Another fertile field for beaver culture could be found in connection with projects for the reforestation with conifers of burned and cut-over timberlands. Many of these areas, cleared by ax or fire, and later covered with a second growth of aspen, willow, and pin cherry, are considered almost worthless. Over much of the northern border of the United States and still larger areas in Canada, such land is generally unsuited for agriculture and would not pay taxes until again covered with valuable forest timber, but would supply ideal food for beavers, and if stocked with these animals could be made to yield an income while the process of reforestation is going on. Not only could many limited areas of private land be thus reclaimed, instead of, as is so often the case, being relinquished as not worth their taxes, but State and Federal lands of this type could also be utilized for the double industry of fur and forest production.

Arctic waste lands.—There is a still more extensive field for beaver culture in the more northern areas of Canada and Alaska, beyond the commercially valuable forest timber, but where aspens and willows are an abundant part of the natural forest growth and where beavers were once so numerous as to yield annually millions of dollars worth of fur. If instead of the old policy of encouraging the extermination of animals by a wild scramble to get their skins, definite areas in these parts should be leased or sold to individuals or companies for raising beavers under control, as private property, this once valuable fur region would again become productive and develop related industries.

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BULLETIN No. 1079

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EXPERIMENTS WITH SPRAY SOLUTIONS FOR PREVENTING INSECT INJURY TO GREEN LOGS.

By F. C. CRAIGHEAD.[1]

Specialist in Forest Entomology, Forest Insect Investigations, Bureau of Entomology.

CONTENTS.

USES FOR REPELLENT SPRAYS AGAINST FOREST AND SHADE-TREE INSECTS.

During the past few years there has been an increasing demand for a practical spray that will prevent insect attack to crude forest products such as green saw logs and timbers used in rustic construction. Numerous requests for such a spray are received by the Bureau of Entomology. These inquiries often number more than a hundred through the summer months.

Although many lumbering firms request a spray for this purpose, it is doubtful whether it would be really practical under ordinary conditions. During the flight period of those insects which cause the injury it would be necessary to apply the spray immediately after felling the trees. It is more practical to prevent insect injury in lumbering operations by some alteration in the methods of management, as by more prompt handling between felling and sawing or by submerging the logs in water, than by spraying.

[1] Resigned December 31, 1920.

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Frequently, however, storms blow over many millions of feet of saw timber. Cases are on record where a single firm has lost in such a manner 100,000,000 board feet. It is a physical impossibility to log these trees promptly and get them to the saw or into a place of safety, although from 40 to 60 days' delay may mean total destruction of the sapwood by borers. It might be feasible, however, to saw these trees into log lengths and spray with some solution that would prevent insect attack for two or three months, or until it was possible to haul them to the mill.

The increasing use of the national forests and parks for recreational purposes has resulted in the construction of many rustic cabins. Insects attacking the timbers in these buildings cause annoying exudations of boring dust and loosen the bark so that later it peels off, thus marring the artistic effect. Much of this injury to rustic work could be prevented by cutting the trees at certain periods and by proper seasoning. Frequenters of summer camping grounds can not always plan to cut the trees at the proper time; in fact, it is more frequently the case that the building is constructed during the summer months and the timber felled at that time—a period when the wood is most susceptible to insect attack.

Thus in both situations it is often the case that the more practical and economical means can not be used.

There is also a considerable demand for a suitable repellent spray against certain shade-tree insects. Wood borers attack various species of living trees, causing considerable injury or death. Under certain circumstances a spray could be used advantageously to repel such insects and prevent oviposition. It would necessarily have to be of materials that would not burn the younger bark, although, except for mechanical difficulties, it would only be necessary to apply the spray to the main trunk and larger limbs, since these are the only parts attacked. Spray materials, the cost of which would be prohibitive for the protection of forest products, might be employed on shade trees.

Under circumstances such as the foregoing it is evident that a practical spray for the prevention of insect injury would be of much benefit and its use should result in a considerable saving of forest products and shade trees.

Owing to the many different insects, their different methods of attacking the logs, the many kinds of wood to be protected, and the exposure to weather conditions, the practical solution of this problem presents many difficulties. Several solutions have been found to meet the requirements, except that they are too expensive or too difficult to apply. In the hope that the results so far obtained may be a stimulus for further suggestions or work along this line the

problem and the preliminary experiments conducted during the years 1916 to 1919 are here presented.

REQUISITES OF A PRACTICAL SPRAY.

It may be impossible to find a single spray solution that can be used with success under all conditions, but it may be possible to obtain good results by using several solutions, each of which is effective under certain conditions. Any spray to fulfill all the requisites necessary for practical effectiveness must possess the following qualities:

IT MUST BE EFFECTIVE AGAINST SEVERAL TYPES OF INSECTS.

Many species of insects attack green timber. Some attack only certain kinds of wood while others show little discrimination. In some cases the injury is caused by the grubs or larvæ feeding beneath the bark or in the wood, or by an adult which bores through the bark and produces larvæ that feed under the bark. According to their method of attacking the wood, boring insects may be divided into the following four groups:

Type 1. Those that lay eggs in crevices of the bark. The larvæ hatching from these eggs then bore through the bark and later into the wood.

Type 2. Those that gnaw a hole through the bark and insert the egg beneath. The larvæ start feeding directly beneath the bark and later bore into the wood.

Type 3. Those that bore through the bark and wood as beetles, to make a suitable place for developing a new brood. The grubs in this case never cause injury.

Type 4. Those that bore through the bark as beetles and lay the eggs beneath the bark. The resulting larvæ feed beneath the bark and loosen it.

The only spray that could possibly be effective against all these types would be one of a disagreeable odor acting as a repellent, thus driving away the adult beetles and preventing oviposition. Poison sprays that will penetrate the outer layers of bark will kill the young larvæ of type 1, but experiments have demonstrated that such materials are not effective against types 2, 3, and 4. In these types most of the beetles do not eat any of the bark or wood as they chew through it and consequently are not poisoned. Possibly a poison combined with a sticky substance that would form a film over the bark and adhere to the mouth parts of the insects might kill them.

Insects of type 4 are not very injurious to saw logs, as they only work beneath the bark and do not enter the wood, but they are important in loosening the bark from rustic work. The others are all injurious to both classes of timber.

IT MUST BE EFFECTIVE ON VARIOUS SPECIES OF WOOD.

The type of bark makes considerable difference in the application of a spray. A bark which is very absorbent, such as that of ash or juniper, readily takes a spray; on the other hand, a smooth bark, such as beech or hickory, will absorb scarcely any of it. Such smooth bark does not hold the spray well but allows it to be easily washed off in the rain. In the latter case poison sprays would hardly be effective. The irregularities of the bark and all crevices must be thoroughly covered.

IT MUST NOT BE LEACHED OFF BY RAIN OR OTHER WEATHER CONDITIONS.

One of the greatest difficulties in the experiments to find an effective spray has been that the solutions are soon washed off by rain. Many of those tried were effective for a few weeks, or until the first hard rain, after which the trees were immediately attacked.

IT MUST NOT BE EXPENSIVE.

Since a considerable quantity of liquid is required to cover a large log by spraying, it naturally follows that the material must be inexpensive or it can not be used. Creosote oil, the most effective material so far tried, is far too expensive. It can be diluted, however, with as much as 4 parts of kerosene, thus materially reducing the cost of the spray without diminishing its effectiveness. For rustic work a much more costly spray can be used than on logging operations.

IT MUST FIRST PREVENT ALL INSECT INJURY FOR FROM ONE TO THREE MONTHS AT LEAST.

Three months' protection by the spray would be sufficient for most purposes. It is usually possible to get logs to the mill or into a place of safety within that time. If it were sufficiently cheap so that a second and perhaps a third application could be made, the solution would need to be effective for only one month; the necessity for more than one application, however, would of course be a handicap. In many cases three months' prevention of damage would carry the tree or log through the danger period—that in which the insect is flying—and natural seasoning during the ensuing winter would prevent further injury.

EXPERIMENTS WITH PREVENTIVE SPRAYS.

During the period of insect activities in the years 1916 to 1920, inclusive, series of experiments were conducted at the Eastern Field Station of the Bureau of Entomology, East Falls Church, Va., to determine the effectiveness of various solutions. These were

materials recommended by various correspondents or suggested by the forest insect personnel. Dr. J. K. Haywood, chairman of the Insecticide and Fungicide Board, United States Department of Agriculture, also gave some very interesting suggestions.

These experiments are to be considered as only of a preliminary character. The objects were chiefly to determine the requisites of an effective spray and to study the behavior of the different types of insects in relation to various treatments and methods of application, as well as to find an effective spray.

The solutions were tried principally on two kinds of wood—pine and ash—although occasionally hickory, juniper, and oak were used. The wood was cut at a time to give the most favorable condition for insect attack—hickory and juniper about January 1, pine and ash about March 15. It was treated immediately or held in a wire insectary until treated. The individual pieces of wood used were 3 feet long and averaged from 6 to 10 inches in diameter.

Insects of all types were represented in the tests. The following were the most abundant and economically the most important: *Neoclytus erythrocephalus* Fab. on ash and hickory, *Xylotrechus colonus* Fab. on oak and hickory, *Asemum moestum* Hald. on pine, *Cyllene pictus* Drury on hickory, and *Hylotrupes ligneus* Fab. on juniper—all of type 1; *Monohammus scutellatus* Say and *M. titillator* Fab. on pine—both of type 2 (no species of type 2 on other woods); various species of Ips, Phloeosinus, and Hylesinus on pine, juniper, and ash, respectively—of type 4; various species of ambrosia beetles on pine and oak of type 3.

From the foregoing it is seen that pine was tested against all four types; ash against types 1, 3, and 4; hickory against type 1; juniper against types 1 and 4; and oak against types 1 and 3. Owing to the seasonal variations in the abundance of the various species of insects the tests were not conclusive every season. For example, in 1918 and 1919 Monohammus was very abundant and attacked all the controls as well as many treated woods, while in 1920 very few were present and not all control logs were attacked. Again, in 1918 Hylesinus (type 4) in ash was abundant, though in 1920 very few of the control logs were attacked. Every year, however, some one type was very abundant on all species of wood used.

The flight period of these insects has a certain bearing on the results, as those species flying late in the season found the logs after they were exposed to weathering for a month or more. Most of the treatments were made about April 1, or 15 days before the flight of the first insects, and unless otherwise stated this time of treatment is to be inferred. With certain materials treatments were made also on June 1 at the time of the first flight of some other species. The flight periods are given in Table I.

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TABLE I.—*Flight periods of beetles used in experiments for the protective treatments of woods with spray solutions.*

	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Woods.
Neoclytus erythrocephalus, type 1.			———	———	——			Oak, ash, hickory.
Xylotrechus colonus, type 1.			———	———	———	———		Oak, hickory.
Asemum moestum, type 1.	——	——						Pine.
Monohammus titillator and *M. scutellatus*, type 2.			———	———	——			Pine.
Ambrosia beetles, type 3.	———	———	———	———	———	———	———	All woods.
Phloeosinus, Hylesinus, and Ips, type 4.	———	———	———	———	———	———	———	Juniper, ash, pine.
Cyllene pictus, type 1.	———	———						Hickory.
Hylotrupes ligneus, type 1.	———							Juniper.

In the extreme northern States the flight period of these insects begins from two to four weeks later. In the Southern States the flight period extends approximately from March 15 to November 1 for all species except *Cyllene pictus*.

Two methods of application were employed—spraying and dipping. Dipping on the whole proved the more effective, as every crevice in the bark was reached; it was also more economical, as a smaller quantity of the solution was required. A round-bottomed galvanized trough requiring only 1 inch of solution in the bottom was used for this purpose. The logs were revolved in the trough until all sides came in contact with the liquid. When carefully done, however, spraying was nearly as effective as dipping and answered very well for practical purposes. It required a fine discharge under strong pressure so that penetration in all crevices was secured.

The treated sticks were placed in several positions: (1) In shaded woods on the ground, (2) in the sun on the ground, and (3) on a platform off the ground in the sun. The location of the sticks had considerable bearing on the results. Those in the woods were always more heavily attacked and those off the ground in the sun least attacked. This can be explained by the more rapid seasoning of the wood off the ground in the sun, which thus offered less favorable conditions for beetle attack, and by the fact that many insects will not oviposit on the upper surface of logs directly exposed to the sun. The logs in the woods were likewise exposed to more humid conditions and the solutions probably leached off sooner. It follows that

the most severe conditions for dipping and spraying tests were presented by those logs in the woods on the ground, and for this reason the discussion of results obtained is based on the results in treated wood placed in this position. Where there was marked difference in the amount of sunlight or in the sun temperature special note is made of the fact.

The thickness of the bark had a certain bearing on the results. Thick-barked pine logs present much more favorable conditions for the attack of all insects concerned. In some cases a treatment was very effective on thin-barked pine logs whereas treated thick-barked logs became heavily infested. The effectiveness of a treatment, therefore, was judged by the results following in the case of thick-barked logs.

TREATMENTS AND RESULTS.

Creosote oil alone.—Pine and hickory dipped and sprayed. No attack three months after treatments except a few insects of type 4 in crevices of sprayed stick.

Creosote oil and kerosene.—All mixtures of kerosene and creosote oil give a tarry precipitate which must be strained out or allowed to settle before the liquid is used in a spray pump. This material was suggested by Dr. A. D. Hopkins.

Equal parts creosote oil and kerosene.—Pine, ash, juniper, and hickory, sprayed and dipped. Results as in the case of creosote oil alone.

One part creosote oil and two parts kerosene.—Treatment as in the next preceding paragraph. Results as in the case of creosote oil.

One part creosote oil and three parts kerosene.—Pine logs dipped. No attack after three months.

One part creosote oil and four parts kerosene.—Pine logs dipped. No attack after three months.

One part creosote oil and eight parts kerosene.—Pine logjs sprayed and dipped were attacked after two months by a few insects of type 4.

Creosote oil alone and mixtures of creosote oil and kerosene gave excellent results. Everything considered, much better results were obtained with them than with any other material. Dilutions of creosote oil containing from 1 to as many as 8 parts of kerosene were effective, and perhaps an even greater dilution would be effective on absorbent barks such as ash or juniper. These mixtures act as repellents (in no cases were insects observed to oviposit where the liquid was present) and they "stand up" very well in wet weather.

One part water-gas tar distillate[2] *and three parts kerosene.*—Considerably more precipitate results from this mixture than from that of creosote oil and kerosene; consequently it is more troublesome to handle. Pine logs were sprayed and dipped. The results were similar to those with creosote oil.

One part coal-tar road surfacing material and three parts kerosene.—Pine logs dipped with this mixture were attacked after 15 days by insects of type 4 and later their condition was but little better than that of the controls.

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[2] A distillate prepared from water gas.

Coal-tar emulsion (prepared by Insecticide Board); 1 part emulsion to 10 parts water.—Pine logs dipped and sprayed were attacked after 15 days by insects of type 4 and later by those of all types. Final results were no better than in the case of the controls.

Crude petroleum.—Pine logs sprayed and dipped with crude petroleum were attacked by insects of type 4 after 15 days and later by those of all types. Final results were no better than with the controls.

Anthracene oil emulsion (prepared by Insecticide Board); 1 part emulsion to 10 parts water and 1 part emulsion to 100 parts water.—Dipped pine logs were attacked by insects of type 4 after 15 days and later by those of all types. The final results were no better than with the controls.

Crude solvent naphtha.—Pine logs dipped with this material were slightly attacked by insects of type 4 after 15 days and later by all types. Final results were but little better than with the controls.

Six ounces of nitrobenzene in one gallon of kerosene.—Pine logs sprayed and dipped were attacked after 15 days by a few insects of type 4 and later by more of the same type. The final results were somewhat better than with the controls.

Fish oil.—Pine logs sprayed and dipped were immediately attacked by insects of type 4 and later by all types. Final results were no better than with the controls.

Two parts fish oil, one part pine oil, and three parts kerosene.—Pine logs sprayed and dipped were attacked after 15 days by insects of type 4 and later by all types. The final results were no better than with the controls.

Kerosene.—Pine logs sprayed and dipped were attacked after 15 days by insects of type 4 and later by all types; results were no better than with the controls.

Sulphite concentrate (furnished by a paper-pulp mill); full strength and diluted with equal parts of water.—Pine logs dipped were attacked after one week by insects of type 4 and later by all types. Final results were no better than with the controls.

Spent sulphite; full strength and equal parts spent sulphite and a commercial miscible oil.—The results in pine logs dipped and sprayed were the same as with sulphite concentrate.

Tree gum (furnished by Gipsy Moth Laboratory); 1 pound of tree gum dissolved in 1 quart of turpentine.—Pine logs treated with a brush were attacked by a few insects of type 4 after two months. The results were much better than on the controls, but the material held moisture in the log and produced much bluing of sap when insects penetrated the bark. The sticky film acted as a mechanical barrier.

One pound of melted paraffin with one gallon of gasoline added.—Pine, ash, and juniper logs were sprayed and dipped and placed in a cage for experiment against insects of type 4. This treatment prevented all attack on the more absorbent bark of ash and juniper. A few insects attacked the pine.

One-half pound of naphthalene dissolved in one gallon of gasoline.—Dipped pine logs were attacked after 15 days by insects of type 4 and later by all. Final results were but little better than with the controls. The naphthalene soon evaporates and no odor is left.

One pound of melted paraffin with one-half pound of naphthalene and one gallon of gasoline added.—Pine, ash, and juniper sprayed and dipped and placed in a cage against type 4 were attacked by insects of this type after 30 days.

One per cent sodium arsenate solution.—Juniper logs dipped and exposed against insects of types 1 and 4 were not attacked after 60 days.

Sixteen parts of 1 per cent sodium arsenate and one part of a commercial miscible oil.—Juniper dipped in this mixture was not attacked after 60 days, but dipped pine was heavily infested by type 4 after 15 days.

Stock solution of kerosene emulsion, the water used containing 2 per cent sodium arsenate.—Pine and hickory logs, sprayed, were attacked by all types possible. The final results were no better than with the controls.

One ounce of sodium arsenate dissolved in one pint of alcohol and added to one and one-half gallons of kerosene.—Very little arsenate went into solution. Pine logs, sprayed and dipped, were heavily attacked after 30 days by insects of type 4 and later by all types. Final results were but little better than in controls. Ash logs, sprayed and dipped, were attacked by one insect of type 1, but the final condition was much better than with the controls. This treatment was repeated on June 1 under similar conditions and with similar results.

One part arsenic acid to nine parts water followed by lime water (arsenic acid 30 per cent AS_2O_5 *by weight, S. G. 1.3000, prepared by Insecticide and Fungicide Board.*—Pine and ash logs were dipped. The pine was not attacked until 60 days and then by only a few insects of type 4. The ash was not attacked. This treatment, under similar conditions, was repeated June 1, and there was no attack after 60 days.

One-fourth ounce of corrosive sublimate dissolved in two and one-half ounces of alcohol and added to one and one-half gallons of kerosene.—Pine and ash were sprayed and dipped. The pine was first attacked after 40 days by a few insects of type 4; there was no other attack. The ash was not attacked. This treatment, repeated June 1 under similar conditions, gave the same results. Although these logs were not attacked by Monohammus of type 2, it is hardly safe to conclude that this treatment would always be effective against them.

Saturated solution of sodium fluorid.—Pine, ash, and hickory were sprayed and dipped. There was no attack for 30 days, and then the logs were infested by all types, though to a less degree than the controls. Little bluing was noted on pine. Although not altogether successful, this solution is worthy of further trial. This treatment, repeated June 1 with conditions as before, gave like results.

Saturated solution of sodium fluorid, 20 parts to one part of a commercial miscible oil.—Pine logs were dipped and sprayed with results as in the previous experiment.

Three ounces of zinc chlorid dissolved in three ounces of alcohol and added to one and one-half gallons of kerosene.—Pine and ash sprayed and dipped. The pine was attacked after 30 days by insects of type 4 and later by all types. Ash was not attacked by type 1. June 1 the treatment, under the same conditions, was repeated with results as before.

Five and ten per cent crude carbolic acid[3] *in water.*—Pine logs, sprayed and dipped, were immediately attacked and heavily infested by all types. The final results were no better than with the controls.

Two and one-half per cent solution crude carbolic acid in water, eight parts to one part of a commercial miscible oil.—Treatments and results as in the preceding paragraph.

Six ounces of carbolic acid in one gallon of kerosene.—Pine, sprayed and dipped, was attacked after 30 days by all types. The final results were no better than with the controls.

[3] Coal-tar oils and acids, 97 per cent; inert matter, 3 per cent.

Carbolic soap solution: One pint crude carbolic acid added to one gallon soft soap, thinned by addition of one gallon of hot water, left to stand overnight, and then diluted with eight gallons of soft water (recommended in literature).—Pine and ash, sprayed and dipped June 1, were attacked by all types after 10 days.

Five per cent solution of nicotine sulphate.—Pine, hickory, ash, and juniper were sprayed, and all were attacked by type 4 within 10 days.

Two teaspoonfuls nicotine sulphate dissolved in three ounces of alcohol and added to one and one-half gallons water.—Pine and ash, sprayed and dipped, were infested by all types after 15 days.

Ten per cent solution of sodium carbonate.—Pine and hickory logs sprayed were immediately attacked by all types possible.

Five per cent solution of a proprietary crude cresol-soap disinfectant.—Pine, juniper, ash, and hickory were sprayed but were all attacked by all types possible.

A strong suspension of whitewash.—Pine logs dipped were heavily attacked after the first rain.

A strong solution of sodium chlorid.—Pine logs sprayed were immediately attacked and their condition was no better than that of the controls.

One part crude pyridin preparation to ten parts water.—This did not mix well. Pine and ash were dipped June 1. After 30 days both woods were infested by all types possible, but were in somewhat better condition than the controls.

One part crude pyridin preparation to ten parts kerosene.—Pine and ash were dipped June 1. After 60 days no insects had attacked either wood. The odor could still be detected on the logs. This material seems to be very promising and deserves further trials.

REMARKS ON POISONS USED.

Several of the more active poisons seem to be effective against certain types of insects, particularly those of type 1. They are especially effective when combined with oils that will penetrate the bark (as the mixture of corrosive sublimate and kerosene) or followed by another solution rendering them insoluble (as arsenic acid followed by lime water). This latter, however, is difficult to apply. They are also more effective when used on absorbent types of bark as ash and juniper.

OTHER EXPERIMENTS WITH INSECTS OF TYPE 3.

The results of the preceding treatments were not conclusive against the ambrosia beetles (type 3) for two reasons: These insects require wood that is moist—at least such wood presents optimum conditions—in which to rear their broods. The logs used in the preceding experiments, averaging only 6 to 10 inches in diameter, often dried so rapidly that they were not suitable for these beetles. At the same time another series of experiments was being conducted in which water-soaked logs were used. These acted as traps, attracting most of the ambrosia beetles.

Consequently, to determine just how effective these solutions were against ambrosia beetles (Table II), the water-soaked logs were thoroughly sprayed with (1) 4 parts kerosene plus 1 part creosote oil, (2) the corrosive sublimate solution as given before, and (3) 1 part crude pyridin preparation to 8 parts kerosene. All the sticks were dried for 24 hours before the sprays were applied. These materials were applied to three pines, one oak, and one ash log, July 28, 1920. The results are given in Table II.

TABLE II.—*Results of experiments in the treatment of water-soaked logs against ambrosia beetles.*[1]

	Controls.			Kerosene and creosote oil.			Pyridin and kerosene.			Corrosive sublimate.		
	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.
Aug. 3	1	1	7	0	0	0	0	0	0	0	0	1
9	0	1	23	1	0	0	0	0	1	0	0	3
13	1	3	27	0	0	0	0	0	0	0	5	6
22	5a	x	x	0	0	1	0	1	0	1a	4	16
27	1a	13	64	1	0	0	0	0	0	1a	0	10
Sept. 1	(2)	(2)	(2)	0	0	0	0	0	0	0	0	4
8	0	1	4	3a	0	0	0	0	1	2a	1	7
18	(2)	(2)	(2)	0	0	2	0	0	0	0	0	1
28	(2)	(2)	(2)	0	0	1	0	0	0	0	0	4
Total ambrosia beetles	2	19	125	2	0	4	0	1	2	1	10	52

[1] Numbers refer to ambrosia beetles attacking except when followed by letter.
[2] Not counted.
a=species of Ips, type 4. x=many ambrosia beetles not counted.

POISONING OF AMBROSIA BEETLES.

To determine whether ambrosia beetles feed on the bark as they bore through it, and consequently whether poison spray could be effective against them, several water-soaked ash logs were dried for 48 hours to remove the excess water from the bark and then completely submerged for 48 hours in a solution of sodium arsenate, 2 pounds to 10 gallons of water.

A wooden frame with a cheesecloth bottom was prepared on the ground, and on supports above this frame a rubber cloth was suspended to keep any rain from reaching the treated sticks. The sticks were placed in the box on the cheesecloth and the cloth was carefully examined every two or three days for dead ambrosia beetles. The treatments were made on May 30, 1920. An untreated control was used in the same position. The results were as follows:

June 8, one dead beetle beneath sticks.

June 15, one beetle boring through bark.

June 23, two beetles boring through bark.

July 23, two to six beetles were in each stick and all galleries contained eggs and various stages of larvæ.

These beetles were evidently not deterred or injured by the poison. At no time were the sticks wet. It is quite probable that the dead beetle found June 8 was not killed by the poison, since no other dead insects were found.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1080

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EFFECT OF LOW TEMPERATURE ON THE HATCHING OF GIPSY-MOTH EGGS.

By John N. Summers,

Scientific Assistant, Gipsy-Moth and Brown-Tail Moth Investigations, Bureau of Entomology.

CONTENTS.

INTRODUCTION.

Extensive study of the gipsy moth (*Porthetria dispar* L.), made in connection with the introduction, establishment, and dispersion of its parasites, has shown that in New England there are agencies of natural control responsible for a considerable mortality among the various stages.

One of these natural-control agencies, which in many cases is the most valuable, acts upon the eggs and causes a failure to hatch. This phenomenon has been termed nonhatch. The results of several years' study are presented in this bulletin.

PRELIMINARY DISCUSSION.

The failure of gipsy-moth eggs to hatch has been common enough to attract attention during the last few years only. As will be shown later, very low temperatures are responsible for this killing, and until about 10 years ago the moth had not spread into territory having such low temperatures regularly. It is probable that even in the older infested area there were isolated pockets which, owing to topography, attained temperatures low enough to kill. Likewise it is probable that a careful examination of some of the egg clusters which

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apparently hatched well would have shown considerable injury. Such points, however, would only have been brought out by an intensive study in the woodland, such as was started later. A few records of entire clusters failing to hatch were made in 1907, notably in North Saugus, Mass., in woodland near the building then used as a laboratory for the parasite investigations.

During the winter of 1911–12 plans were perfected for an extensive and intensive study of the gipsy moth under natural conditions. These plans called for the selection of a considerable number of small areas, well proportioned as to type of tree growth and so placed as to be representative of the entire infested area. The areas designated as "observation points" were to be followed closely during the entire year, with careful notes on hatching of the gipsy-moth eggs, feeding of the larvæ and the injury done by them, the increase or decrease of the infestation from year to year, and many other phases of the subject. As the entire problem was built around the degree of infestation, it became necessary to have an accurate knowledge of the number of egg clusters present in each "point." Therefore, each fall or winter a careful count was made, and it was this counting which brought forcibly to the attention of those engaged in experimental work that some agency was playing a considerable part in the control of the moth by killing the eggs.

The nonhatch problem did not receive extensive experimental attention until the fall of 1915, when preliminary work was started.

FIRST INVESTIGATIONS.

At first considerable time was devoted to the study of the nonhatch eggs themselves. Such individual eggs collected a few months after the end of the normal hatching season, as well as those 1 or 2 years old, were all light gray in color. Careful dissection showed that this appearance was due to a complete, closely woven mat of fungus mycelium which was pressed closely against the inside of the shell and entirely surrounded the dead embryo. The presence of this organism in all the nonhatch eggs made it appear that there might be some connection between it and the death of the embryo. Cultural studies were made, and a considerable number of infection experiments were carried on, which, however, failed to give more than vague evidence that the fungus was ever more than a saprophyte. It is possible that this organism, belonging in the large and rather indefinite genus Fusarium, is, under conditions particularly favorable to itself, a true parasite. However, extensive dissections and cultures made of nonhatched eggs as soon as it was shown that they were not going to hatch have yielded no positive evidence of its being parasitic.

The first real study of nonhatch in the field was begun in the fall of 1916.[1] Previous to this a series of egg-cluster collections had been made, beginning in August, 1915, and continuing at monthly intervals until just before normal hatching time in the spring of 1916. Six sets of these collections were made, five being obtained at chronic

[1] The writer wishes to express his appreciation of the able assistance given him by Mr. H. I. Winchester, who helped with the experiments for almost the entire time they were conducted. During the time the writer was in the Army, Mr. Winchester conducted all the experiments, and to him belongs the credit for planning and making the summer observations on hatching.

nonhatch points—that is, points at which considerable nonhatch had been noted each year since the start of the "observation-point" investigations. The sixth set, collected as controls, was obtained from a point which had not shown nonhatch. All the clusters thus obtained were kept in a cool place at the laboratory from the time of collection until just before normal hatching time in the spring. Each cluster was then placed in a glass tube and allowed to hatch normally. All larvæ thus produced were counted, and later, when hatching had ceased, the remains of the clusters were rubbed over a cheesecloth sifter to separate the unhatched eggs from the hair with which the egg cluster is made.

As soon as the records from the six sets of collections could be studied it was seen that there appeared to be some connection between nonhatch and cold weather, for clusters obtained from the five points before our normally cold months hatched almost perfectly, while those obtained after the cold season began failed to produce larvæ.

This suggestion opened up a new line for investigation, and accordingly three sets of weather instruments, each consisting of a recording thermometer and a recording hygrometer, were procured and placed in small instrument houses. As the instruments required considerable attention the three houses were placed at points in the towns of Westford, Acton, and Dover, Mass., two being chronic nonhatch and the third no nonhatch, not very many miles from the Melrose Highlands Laboratory.

The instruments were started September 1, about the end of the laying season, and were run continuously until about May 1, the normal hatching time. They were tested for accuracy at frequent intervals to insure true records, a discussion of which will be given later.

METHOD OF HANDLING ALL EGG CLUSTERS USED IN EXPERIMENTS.

Egg clusters when brought in to the laboratory were placed where they would be kept cool but not exposed to severe weather. Just before normal hatching time, which is about May 1 at Melrose Highlands, each cluster was placed in a glass tube large enough to contain it unbroken. This tube was closed with a cotton plug. As soon as hatching was well advanced, the larvæ were removed from the tubes and counted. At the end of the hatching season, the remains of each cluster were rubbed over a cheesecloth sifter, made by stretching fine-meshed cheesecloth over a frame, to separate the unhatched eggs from the mass of hair with which all clusters are made. These unhatched eggs were then examined microscopically and divided into infertile and nonhatch, the records of each cluster being kept separately.

MONTHLY COLLECTIONS.

Some of the clusters collected during the season of 1915–16 proved to be old nonhatch. During the winter, after the new clusters have become weathered, it is difficult to distinguish between old and new. To make certain that only new clusters would be collected, a sufficient number of these were marked with lumber crayon at the end of each laying season at the same six points used for the collections

of 1915–16. Ten clusters were collected at each point on the first of each month, beginning in September and ending in April. Subsequently they were handled exactly as described.

As the sets of weather instruments were located at three of the collection points, the records obtained from these are the most valuable. The other three, however, were kept as collection points for purposes of comparison.

MONTH'S EXPOSURE.

As controls on the naturally produced egg clusters obtained in "monthly collections," a series of experiments were conducted with clusters produced at the laboratory. To obtain these, vigorous males and females were mated in a small cage, and later the females were confined in small tin boxes, where they deposited their eggs upon pieces of thin wood.

Ten such clusters were tacked to trees at each point where there were weather instruments and allowed to remain in the open just one month. The first set was out from September 1 to October 1, the second from October 1 to November 1, and so on. The last set placed out April 1 was brought in just before hatching time. After exposure the clusters were handled as in all the other experiments.

NATURAL PROTECTION.

Notes taken in connection with the "observation-point" investigations showed that in certain localities there was considerable difference in hatching on different parts of the trees. Clusters found under roots or in cavities close to the ground, as well as those fully exposed close to the ground, appeared to hatch completely, while those higher up failed to do so.

Investigation at a number of chronic nonhatch points proved that in general it would be rather difficult to find enough clusters naturally deposited where they were wanted. Therefore, at each of the six points from which monthly collections were obtained 100 new clusters were cut from the trees and tacked back in the following positions:

Twenty-five clusters were tacked under roots or in cavities close to the ground. Usually these were covered with leaves.

Twenty-five at the base of a tree close to the ground but entirely in the open.

Twenty-five on the trunk well up from the ground, usually about 5 feet.

The remaining 25 were brought in to serve as controls.

Collection of these clusters was made just before hatching time each spring.

ARTIFICIAL PROTECTION.

Originally these experiments were planned when the fungus found in the nonhatch eggs was looked upon as a possible cause. Various means were tried of protecting the clusters against infection, but most of these were abandoned when the true nature of the fungus became apparent.

Two experiments in artificial protection were continued. The first, by means of a wire cage suspended between trees, sought to protect the clusters contained therein from any influence the tree

might have and at the same time expose them fully to all actions of the elements. The second was an endeavor to protect the clusters from wind and rain or snow, but to expose them to fluctuations in temperature and atmospheric moisture. This was accomplished by placing them in open inverted preserving jars and holding them up near the bottom with wire screen. The jars were wired to tree trunks.

Both types of artificial protection were performed with laboratory-bred clusters and were put out at a considerable number of chronic nonhatch points. The clusters were brought to the laboratory in the spring and handled like all the other experimental clusters.

EXPOSURES OF CLUSTERS TO ONE SEVERE DROP IN TEMPERATURE.

After results from some of the other experiments had pointed rather conclusively to low temperatures as the cause of nonhatch, it was desirable to gain more information on the degree of cold and the extent of exposure necessary to kill.

It was planned to expose sets of clusters to a single severe drop, beginning with —15° F., apparently the temperature at which the first killing took place. It was hoped that a complete chain would be obtained from —15° downward as far as the thermometer goes at the points where the weather instruments were placed. This was not found to be possible, as one could not foresee the temperature fluctuations. A certain number of such sets of clusters, however, were exposed.

The sets of laboratory-bred clusters were placed near the weather instruments and allowed to remain until they had been exposed to a single drop of at least —15°. They were then brought in and handled like other clusters.

TEMPERATURE RESISTANCE.

Sets of 10 laboratory-bred clusters were exposed during the winter in small wire cages along the line marking the northern limits of the gipsy-moth area. These were placed in towns from which the Weather Bureau office at Boston obtains records, so that a close record of the cold might be available, for it was desired to note the effect of as extreme cold as possible.

These remained out all winter until just before hatching time, when they were brought to the laboratory.

SUMMER SURVEY OF HATCHING.

Each summer for three years, after the hatching season was over, an extensive series of observations on hatch was made in the field. Practically the entire area of infestation was gone over from the most southern limits to the most northern, and a very large number of observations were made. Fortunately it was possible to make these observations after two very cold winters and one very mild one, the latter coming between the two cold ones.

WEATHER.

The instruments located at the three points gave records of temperature and relative humidity. As soon as these records for the

first year could be compiled and studied it became evident that humidity could play little, if any, part in the killing of the eggs. As stated elsewhere, the factor responsible for nonhatch acts during the cold months of December, January, and February, during which the amount of moisture in any given space is very low. This in itself would hardly be proof, as low humidity might have some effect. There was no appreciable difference, however, between the humidity records from the three points, two of which showed nonhatch while none was obtained from the third. Humidity records for succeeding years have only served to substantiate those obtained the first year.

Temperature lines for the three points followed one another closely until December, but as soon as severe cold weather set in the difference became very marked.

At the point which had never yielded nonhatch the coldest days found the mercury little below zero, while at the other two, temperatures of from —20° F. to —30° F. were recorded, and during most of the time they were from 15° to 25° colder than the first point. The two exceptions to this were during December, 1917, and February, 1920, when the temperature at the warmest point fell to —15° and —16° F., respectively, for the only times during the four years that records have been taken. These resulted in many eggs failing to hatch.

Temperature records obtained from the instruments during four consecutive winters show that the cold weather comes from the last part of December to the first of March, with the lowest drops in January and February. The first winter, 1916–17, was only moderately cold, with the greatest drop coming in February. The next winter, 1917–18, was extremely cold in December, January, and February, and following this came the unusually mild winter of 1918–19 with hardly a drop below zero. This in turn was followed by another extremely cold winter which made conditions almost ideal for our experiments. The mild winter of 1918–19, coming as it did between two that were very cold, made comparison of the records of all three seasons very valuable.

The Weather Bureau office at Boston obtains records regularly from 50 substations in the gipsy-moth area. A study of these records shows that in general the drops in temperature become lower as one goes northward. Along the coast, however, due to the modifying effect of the ocean, the cold is nowhere nearly as severe as it is farther inland. Also, one may find small areas having much lower temperatures than the surrounding country, due to the topography which induces that phenomenon known as air drainage, the cold air flowing down into the lowest spot and settling there.

RESULTS OBTAINED FROM EXPERIMENTS.

Monthly collections, as stated on page 3, were made at five chronic nonhatch points and one control point where no nonhatch had ever been found. Three of these had weather instruments, so that it was possible to check results against temperature records.

Collections made at the nonhatch points up to February 1, 1917, the only month having severe cold that winter, hatched completely, while those obtained March 1 and afterwards were all nonhatch. Those laboratory-bred clusters exposed during the month of February were all killed, but those exposed every other month hatched completely. The next winter severe cold came in December, January, and February. Collections made up to December 1 gave complete hatch, while neither those collected after that date nor the month's exposure clusters for the three cold months hatched. The next winter, 1918–19, was mild, and all clusters for all months hatched completely. The winter of 1919–20 was another very cold one, with the extreme cold coming in January and February, resulting in hatch records identical with those of the other cold periods for both monthly collections and month's exposure.

During the entire four winters only two drops greater than —10° F. were recorded from the point which had never shown nonhatch. The first, in December, 1917, —15°, resulted in about 50 per cent of the eggs in the monthly collections and month's exposure clusters being killed. The second drop, —16°, came in February, 1920, with the same effect on the eggs.

The method employed in determining the extent of injury to the eggs in the various experiments may need explanation. In the first place, care was taken to provide plenty of control clusters for all the experiments and these were treated exactly like those for which they were controls, except that they were not exposed to conditions at the various points. Clusters which did not hatch at all could be listed as complete nonhatch. However, in figuring percentage of hatch in partially hatched clusters, the number of infertile eggs was deducted first, as they could not possibly have hatched.

A careful comparison of the temperature and nonhatch records has led to the conclusion that —20° F. is about the highest point at which all the eggs in a cluster will be killed and a further drop will make it more certain that all exposed eggs will be killed. There is reason to believe that the resistance of the eggs depends to some extent upon their vitality, as would be only natural. Evidence on this point was secured from the sets of clusters which were only exposed to a single severe drop in temperature. One set exposed to —22° F. was entirely killed, but a very few eggs in a set exposed to —23° F. hatched.

There are no records of any eggs hatching after being exposed to a temperature of —25° F. or lower, whether they were subjected to one such exposure in the "single drop experiments" or several, as sometimes happened with the "month's exposure" sets. On the other hand, exposures to —15° and —16° F. killed half the eggs in the clusters, but no temperature above —20° F. killed an entire cluster. Various records of exposure to temperatures higher than —15° F. showed no injury at all.

The conclusion, therefore, is that the vital point for complete killing lies between —20° and —25° F., with an absolute certainty that all eggs exposed to any further drop will be killed.

The artificial protection experiments may properly be considered after the monthly collections and month's exposure, for the data secured from the first in a way serve to substantiate those ob-

tained from the last two. All of these were conducted at chronic nonhatch points.

Those clusters placed in the wire cages were entirely removed from any influence the trees might have upon them and were fully exposed to all actions of the elements. Very little information was obtained from this series beyond the fact that clusters reacted the same way no matter how they were placed.

During the cold years all of these clusters were killed, as were those naturally on the trees. After the mild winter they all hatched completely.

Those clusters in the inverted jars received a considerable amount of protection, as they were in no way affected by storms. Low temperature could act upon them freely and to a certain extent the atmospheric moisture could do so, for the jars were open at the bottom, allowing air to ascend into them when it became warm. No rain or snow could reach them, however, and as a result they remained perfectly dry during the entire winter, as was proved by numerous observations. They were therefore not frozen or covered with ice, as were many of the clusters in the open.

These clusters were only exposed to temperature and atmospheric moisture. It has been shown already that humidity can play very little, if any, part in killing the eggs; therefore it may be considered that if these eggs were killed temperature must have been responsible. To corroborate this conclusion all eggs exposed in this manner failed to hatch after the cold winters, but hatched perfectly after the mild one.

Experiments in natural protection were suggested by notes taken in connection with the "observation point" investigations, as has already been noted. It was found that those placed close to the ground at nonhatch points, whether in cavities, under roots, or in the open, hatched completely, while those high up were killed. At first sight snow appeared to be the protecting factor; and this supposition was borne out later by actual observation, though it was some time before all variations could be reconciled with this theory. To afford protection the snow had to cover the clusters during every severe cold spell, which it did not do because of the countless variations in its depth, and it was only after a long series of observations in the woods that a true appreciation of the variableness of this factor became apparent. Depth even immediately after the cessation of a storm varied enormously, particularly if the snow was light, for every breath of air induced drifting. Many times also the eddying of the wind around the tree trunks left the snow piled against one side and blown away from the other. The resulting depression served to expose some clusters while others remained covered, a fact which explains why clusters close to the ground were killed and those much higher hatched.

A close following of the snow history of a section during the winter showed great fluctuations in depth, when measured on the trunk of a tree small enough to be unaffected by the wind eddies mentioned above. At the end of a storm the snow would be piled to a certain height on the tree; then gradually settling would take place, until after the lapse of a few days there would be several inches difference

between the new level and the old. A new storm might then come and cause the level to rise again. So it went during the entire winter, and clusters on the border line of snow protection were alternately exposed and protected. Observation made on some such clusters proved conclusively that the snow is the medium of protection.

There remains only one series of experiments to be discussed, namely, temperature resistance, which was conducted for two years only. As it developed, the first year selected for this type was, very opportunely, the mild winter 1918–19. The only killing of eggs for that year that was recorded in our experiments developed in some of these sets of clusters exposed at the northernmost limits of the gipsy-moth area, in the only towns from which records anywhere near —20° F. were taken. After the next winter, as was to be expected, none of the clusters in this series hatched.

RESULTS OF SUMMER SURVEY OF HATCHING.

A few observations made in the field after the end of the hatching season which followed the extremely cold winter of 1917–18 disclosed the fact that there was an unusual amount of nonhatch. This gave a very good opportunity for a careful study under natural conditions. Accordingly, extensive plans were made to extend observations over as large a portion of the gipsy-moth area as possible. Results obtained from experiments had pointed strongly toward low temperature as the causative factor of nonhatch. To a certain extent, however, the experiments had an element of artificiality, and it was desired to obtain as much information as possible under purely natural conditions.

The plans called for observations on hatch of egg clusters on trees, undergrowth, stumps, débris on the ground, boulders, stone walls, and other objects. Many factors were taken into consideration, such as nearness to the ocean and bodies of fresh water, height of land, degree of exposure to prevailing winds, favorability or unfavorability of food plants and the abundance or scarcity of these, the degree of gipsy-moth infestation, and any other points which might present themselves. These observations were taken during the three summers 1918, 1919, and 1920.

The observations taken in the summer of 1918 disclosed a complete nonhatch of all clusters above the snow-protection line in Maine and New Hampshire, with the exception of a section along the seacoast. This section showed only a partial hatch. All clusters found on the ground or on other objects close to the ground where they could be snow-protected hatched completely. Hatching above the snow-protection line in Massachusetts, with the exception of a coastal section which included all of Cape Cod, was poor with a considerable number of whole clusters killed, particularly in the northern and northeastern parts. Hatching of low clusters in all this area was uniformly good.

In Rhode Island and along the coast as far north as the Massachusetts-New Hampshire line the hatch was almost complete.

Apparently the modifying influence of the ocean overcame the severe cold at least enough to prevent the temperature from dropping to the killing point all along the coast of Rhode Island and Massa-

chusetts. The area over which this modifying effect protected the eggs was wide in Rhode Island and Massachusetts, but it gradually narrowed northward until at Portsmouth, N. H., the only modification was right on the coast, and even there some of the eggs were killed. Farther north the cold was too great to be overcome sufficiently to allow the egg clusters to hatch completely, and only a partial hatch was recorded.

The Weather Bureau records show that the foregoing hatch records are just what would be expected if low temperature was the cause of nonhatch.

Bodies of fresh water apparently had no influence on the hatch.

Elevation made no difference except in sections right on the border line of killing cold, that is, sections which as a whole had temperatures not quite low enough to kill. In these sections clusters in low areas were killed while those on the higher levels escaped, a difference caused by cold draining into the low land and settling there.

The object upon which the clusters were placed had no effect, as no matter what it was, if they were above snow protection in a locality which had severe cold, they were killed.

Considerable observation on the possible influence of the food plants failed to show any difference. Records taken in any locality were uniform no matter what species of tree the eggs were laid upon, and irrespective of the abundance or scarcity of favored food. Of course this latter factor had some bearing on the abundance of clusters, but it made no difference in the nonhatch.

At only one place, a location right on the coast in Rye, N. H., was it possible to make a direct comparison between egg clusters completely exposed to the prevailing winds and others well protected from them. In a little grove about a quarter of a mile from the sea, exposed on its ocean side to the full sweep of northeast storms, the clusters on the windward side had the hairy covering entirely weathered away, leaving the eggs uncovered. These did not hatch. On the other side of the same grove other clusters were found which had not been deprived of their hairy covering. These hatched almost perfectly.

Following the mild winter of 1918–19, the same localities were visited again. Every cluster found, no matter what its position on the tree or other object, hatched perfectly. In fact, there was not a single nonhatch cluster found during the progress of the summer survey; neither was there one reported by men engaged in other branches of the gipsy-moth investigations.

The winter of 1919–20 was a complete contrast to its predecessor but was almost exactly the same in temperature as that of 1917–18. There was a considerably greater fall of snow in some localities, which gave protection to a greater number of clusters. Observations after this winter gave the same results as those after the other cold one, except that in some places which had more snow than during the other cold winter a greater number of clusters had hatched.

All of the results of the summer survey observations, compared with records of temperature obtained by the Weather Bureau, serve to add conclusiveness to the fact that low temperature is the cause of nonhatch.

EFFECTIVENESS OF NONHATCH.

Nonhatch as an agency in the natural control of the gipsy moth reaches the maximum of its importance in those sections of the infested area which have, some time during each winter, cold severe enough to kill all eggs exposed to its action.

The principal protection from this killing cold is afforded by the snow; and the upper limit of this protection, measured from the ground, has been designated as the snow-protection line. It must not be supposed that this line has any definite limits, for the depth of snow is an extremely variable factor.

To determine the value of nonhatch as an agency in gipsy-moth control it is therefore necessary to determine the distribution of the egg clusters on the trees, the factors which influence this distribution, and the proportion placed above the snow protection line. Fortunately a considerable amount of information along these very lines has been obtained during the progress of the "observation point" investigations.

The count of egg clusters made at each "point" was divided into two sections. The dividing line was marked at 5 feet from the ground on the trunks of the trees. The count of clusters above this line was known as the high count, of those below as the low count. Such a division was necessary on account of the work involved, which made impossible the complete counting of an entire point at one time. Many times also snow would prevent a low count but would not prevent the high count being taken. Five feet was chosen as a convenient point well above the usual snowfall.

As the clusters were recorded with reference to their position above or below this 5-foot line, it will have to be the dividing line considered in studying the distribution of clusters on the trees. A depth of snow to the extent of 5 feet is almost unknown in most sections of the gipsy-moth area, so we may safely consider that all the exposed egg clusters above 5 feet will be killed if the temperature drops to —20° F. or lower. At the same time there will probably be a considerable number of clusters between the 5-foot level and the top of the snow during at least one period of severe cold, so that we are conservative in using the high count as a basis for figuring benefit derived from nonhatch.

A careful consideration of the egg-cluster records from the "point" notes, which were taken during seven consecutive years, shows that on the average 70 per cent of the clusters are laid above 5 feet. An average of nearly 900 individual counts showed 72 per cent.

The deposition of clusters is influenced largely by the ground conditions. If there is no underbrush and if débris, such as dead wood, bark, etc., is not present or if the ground is wet, most of the clusters will be well up on the trees. On the other hand, if débris is abundant, if there is much undergrowth, or if, as often happens in New England, there are stone walls running through the woods, a large proportion of the clusters will usually be found close to the ground.

It is not possible to say just what causes the differences, but the "point" notes show that they are as stated. In addition, the records

show that unless some change takes place, such as removing the débris or increasing it by brush from cutting, the proportion of those above and below the 5-foot line will remain approximately the same. Having determined 70 per cent as being the average proportion of egg clusters laid above 5 feet, we can see just how valuable as a means of control nonhatch may be where the cold is sufficiently severe to kill all unprotected clusters.

This particularly desirable state of affairs can not be looked for in a large part of the territory, for the temperature does not go low enough. The "point" notes show all variations between the above-mentioned percentage and no killing at all. Occasionally there is a mild winter with no low temperature and all eggs hatch the following spring.

As nonhatch is caused by a temperature of from —20° to —25° F. we can only expect to find it in territory subjected to such low degrees. Temperature records obtained from the 50 stations of the Weather Bureau which are located in the present area of infestation show that any prophecy as to just what would happen in any locality would be quite useless. If the law of averages may be considered in this case, killing cold will occur in a majority of years in all of Maine and New Hampshire except a narrow area along the coast. In Massachusetts such cold, at least as reported by the weather stations, is the exception, but there appears to be a greater tendency toward it in Worcester County and the northern part of Middlesex County. The remainder of the infested area, with the exception of the northern part of Windham County in Connecticut from which extreme low temperatures are occasionally reported, apparently escapes cold severe enough to kill the eggs.

These general conclusions, based as they are upon Weather Bureau records, apply to the sections as a whole. Local conditions, however, vary to such an extent that we may find nonhatch in restricted areas in sections from which temperature records would apparently exclude it. "Observation point" investigations prove this to be particularly true of northern and central Massachusetts.

It is possible that nonhatch is responsible for the slow increase of the gipsy moth in many localities where food conditions would seem to point to just the reverse.

EFFECTS OF COLD ON PARASITES.

There is reason to suppose that a drop in temperature low enough to kill the eggs will have some effect upon the imported parasites, particularly those which attack the eggs themselves. Two egg parasites, namely, *Anastatus bifasciatus* Fonsc. and *Schedius kuvanae* How., have become well established in New England. The former passes the winter as a full-grown larva within the egg of the host. No collections of eggs parasitized by *Anastatus bifasciatus* have been made after extremely cold weather for the specific purpose of determining the effect of cold upon this parasite. It was noted, however, that there was a large percentage of dead parasites in a bulk collection of eggs obtained after the cold winter of 1917–18. The locality from which this collection came has been used for a number of years as a source of material for new colonies, and eggs

collected there had each year shown a high percentage of parasitism. After the above-mentioned cold winter the parasitism was of decidedly lower percentage, but two years later it had about reached its former high point.

In the long run it is doubtful if the cold would have any very serious effect upon the general abundance of *Anastatus bifasciatus*. Even though all the parasites as well as all the eggs above the snow protection line were killed, the proportion of parasites to eggs would be the same in those egg clusters protected by the snow, for there is very little difference in percentage of parasitism between eggs near the ground and those above 5 feet. Therefore, there would be the same proportion of adult parasites to attack the eggs the next summer as if all parasites and all eggs came through the winter safely.

As the result of particularly adverse conditions a decrease in parasitism by *Anastatus bifasciatus*, such as was evidenced at the stock colony, may occur for a few years, but no doubt there is a gradual recovery.

Schedius kuvanae has received some rather severe setbacks from cold winters. It hibernates as an adult, principally in leaves and rubbish on the ground, and in such position it would be well protected from the cold if there was plenty of snow during each period of extremely low temperature. Apparently such protection has not been present in a number of cases, for there are records of colonies from which recovery of parasites was difficult after a severely cold winter.

Some of the other imported parasites may be killed by low temperature, but very little information has been obtained to confirm this idea.

Further investigations may throw more light upon the relationship of low temperature to parasite mortality.

CONCLUSIONS.

The failure of gipsy-moth egg clusters to hatch is caused by low temperature.

An exposure of between —20° and —25° F. is necessary to kill entire clusters, though some eggs in each cluster may be killed by an exposure to —15°. No eggs will survive an exposure to lower than —25°.

When the temperature is low enough, an average of 70 per cent of the clusters may be killed, but this desirable condition develops only in the northern part of the infested area and only during certain years.

Snow will protect the egg clusters from the effects of the cold if it covers them; therefore, the greater the depth of snow the larger the number of clusters that will hatch the following spring.

The benefit derived from nonhatch may vary after a cold winter from 70 per cent of the clusters killed in the northern part of the area to no injury to the eggs in the southern section.

Maine and New Hampshire receive the greatest benefit from nonhatch. Central and northern Massachusetts also derive considerable benefit particularly in restricted localities. Connecticut, Rhode

Island, the southern and eastern parts of Massachusetts, and the coastal section of New Hampshire derive very little, if any, benefit, for even after the coldest winters nearly all eggs hatch.

Nonhatch is of a periodic nature, as occasionally New England is visited by a mild winter, after which practically all eggs hatch.

The benefit derived from nonhatch is offset to some extent by the injury cold weather works upon the parasites of the moth.

As temperature is entirely uncontrollable, there is no way that man may direct its action against the gipsy moth.

Finally, too much reliance must not be placed on nonhatch as a means of control, for it occurs only after the egg clusters have been exposed to the proper degree of cold.

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UNITED STATES DEPARTMENT OF AGRICULTURE

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BIOLOGY OF THE PAPAYA FRUIT FLY, TOXOTRYPANA CURVICAUDA, IN FLORIDA.

By Arthur C. Mason, *Assistant Entomologist, Fruit-Insect Investigations, Bureau of Entomology.*

CONTENTS.

INTRODUCTION.

The occurrence in 1905 of a newly introduced species of fruit fly (*Toxotrypana curvicauda* Gerst.) [1] attacking the papaya (*Carica papaya* L.) in south Florida was the occasion several years later for a preliminary investigation and paper on the insect by Knab and Yothers.[2] Technical descriptions of the insect, together with its distribution and history, are recorded therein, and also some notes on its habits. In recent years the pest has assumed much greater economic proportions, due to the increasing production of the papaya from a commercial standpoint, and also to the spread of the insect over nearly all portions of the State where papayas are grown. Hence a careful study of its biology and control was undertaken by the writer.

It is the purpose of this bulletin to present an accurate account of the life history and seasonal history of the insect, together with its habits and the factors influencing its development and spread. The methods of control as far as worked out are also given.

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[1] Dipterous family Trypetidae.

[2] Knab, Frederick, and Yothers, W. W. Papaya fruit fly. In Jour. Agr. Research, vol. 2, No. 6, p. 447–454, pl. 41–42. 1914. Literature cited, p. 453.

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DESCRIPTION AND LIFE HISTORY.

EGG.

The eggs (Pl. I, C. *b*) are of very unusual proportions, being long and slender, somewhat club-shaped or fusiform, with a long cylindrical stalk. The average length is about 2.5 mm. and the greatest diameter is 0.2 mm. They are inserted into the seed cavity of the fruit from the long ovipositor of the female. The stalk sometimes remains partly in the flesh, although the eggs are never placed there as the young maggots seem unable to survive there. They always occur in clusters, and usually there is only one cluster to a fruit. The cluster consists of from 6 to 20 or more eggs, which are always fastened together by an adhesive substance on the surface of the eggs. One female, according to Knab and Yothers, is capable of laying 103 eggs, all of which are disposed of at about the same time.

The eggs require from 12 to 14 days to hatch at any time throughout the year. Although the other stages are longer in winter than summer, the egg seems not to be affected by climatic changes. This point was determined by cutting open infested fruits at definite intervals after they were stung. Usually an adult would oviposit in several fruits on a tree the same evening. It was then possible to cut one of these on each of several successive days until the eggs were found to have hatched. Even in the fruits which had been cut the eggs would complete their development if the halves were placed together, provided they were several days old when first exposed to the light and air. With freshly laid eggs this was not found to be true. Many attempts were made to rear the eggs artificially after removing them from the fruit but without success. When dissected from the fruit and placed on a piece of leaf or fruit pulp over a plug of wet cotton in a vial inverted in water, as practiced by Back and Pemberton [3] with melon-fly eggs in Hawaii, they failed to develop. Even though the conditions of heat and moisture were apparently the same as in the fruit they did not hatch.

When ready to hatch the eggs split longitudinally along the micropylar half and the maggot escapes, leaving the stalk end intact.

LARVA.

The young maggots on hatching from the eggs begin at once to feed on the coating of the seeds. They remain for about the first half of their existence within the seed cavity, feeding on the seed coverings and other fibers there. Many of the seeds become de-

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[3] Back, E. A., and Pemberton, C. E. The melon fly in Hawaii. U. S. Dept. Agr. Bul. 491, p. 18. 1917.

tached by this process, and the loose seeds in the fruits serve as an indication of their presence. When newly born the maggots are almost transparent, but soon assume a shining, dirty white color while in the seed cavity. Later on, as they continue to develop, they eat into the flesh of the fruit, first close to the cavity and then working farther out until, when mature, they are close to the skin. They have then only to eat a hole through the rind to escape. During this latter part of their life they become a rich golden yellow color, like the color of the fruit on which they are feeding. The presence of the maggots in the fruit usually causes it to turn yellow and ripen prematurely. This is a distinct advantage to the larvæ, for they do not like the juice of the green fruits and usually remain around the seed cavity until the flesh begins to soften.

The mature maggots (Pl. I, C, *a*) average about 11 mm. in length, are subcylindrical in shape, and taper anteriorly to the mouth.

The length of time required for their development varied from 10 to 27 days in a large number of tests. The cooler weather of winter prolongs somewhat the length of the larval stage. Conditions unfavorable to the larvæ, such as the fruit decaying or the maggots being removed from the fruit, will cause them to transform before the normal time. On the other hand, if the conditions are favorable the larvæ may remain in the fruit for several days after reaching maturity. The average time for this stage is 15 days.

They make their escape by eating a hole through the skin and dropping to the ground. As a rule, when one escapes the others will follow in rapid succession, and often all emerge from the same exit hole. If the fruit has already fallen from the tree the maggots go into the ground immediately under it; if the fruit is still on the tree they drop to the ground. Often a larva will remain partly emerged from a fruit and continue a wriggling, twisting motion for an hour or more before finally dropping. When once on the ground the maggots immediately bury themselves and never wander around on the soil. The transformation is completed within a few hours after entering the ground. The period of exposure from the time of leaving the fruit to entering the soil ordinarily would be only a minute or two, and consequently there would be little chance for parasitism here. Very rarely a maggot will pupate inside a fruit.

The number of maggots in a single infested fruit sometimes runs up as high as 40, although ordinarily there are about 15 or 20. A very small fruit may have only 2 or 3.

If confined in breeding jars where no soil is present the larvæ usually will not pupate. In a glass stender dish or Petri dish the mature maggots would remain in the larval stage for three or four days, continually crawling around the dish. After several days they

attempt to pupate, but many of them die before completing the transformation. Even when they succeeded in pupating, the adults never matured from them. Evidently this is due to a lack of moisture, which seems to be a vital factor to all stages of development in this insect.

PUPARIUM.

In common with other fruit flies, this insect passes the pupal stage in the ground. The puparia occur naturally under the infested trees in the soil, for, as stated above, the maggots do not travel around, but go into the ground where they fall. The average depth of the puparia is 2 inches, although they vary anywhere from the surface to 3 inches deep, and sometimes occur also under rock and rubbish on the surface. The moisture in the earth seems to determine largely this point, for they go down until they can get into damp soil. Very rarely one is found inside the fruit either on the tree or on the ground.

The puparia (Pl. I, B) are of a stout, subcylindrical form with rounded ends and vary in length from 8.5 to 12 mm. The size is no indication of sex, for from 100 of the smallest ones obtainable about an equal number of males and females emerged. The color of the puparia varies all the way from a light ferruginous yellow to dark brown or almost black. This color in no way indicates their age, for some remain light colored throughout their existence.

The pupal stage was found to vary from 18 to 44 days in breeding out several hundred in all months of the year. Aside from the temperature changes the effect of the moisture is a very large factor in this regard. Under favorable conditions of moisture the largest number of the adults will emerge after 18 to 20 days in hot weather, but in winter this runs up between 30 and 40 days on the average. Hooker [4] found it to last from 17 to 21 days in Porto Rico. Moisture, even more than heat, seems to be the determining factor. Lack of moisture will prolong very materially the pupal stage and if continued will prove fatal. On the other hand, excessive moisture will kill the puparia. The following data prove this point:

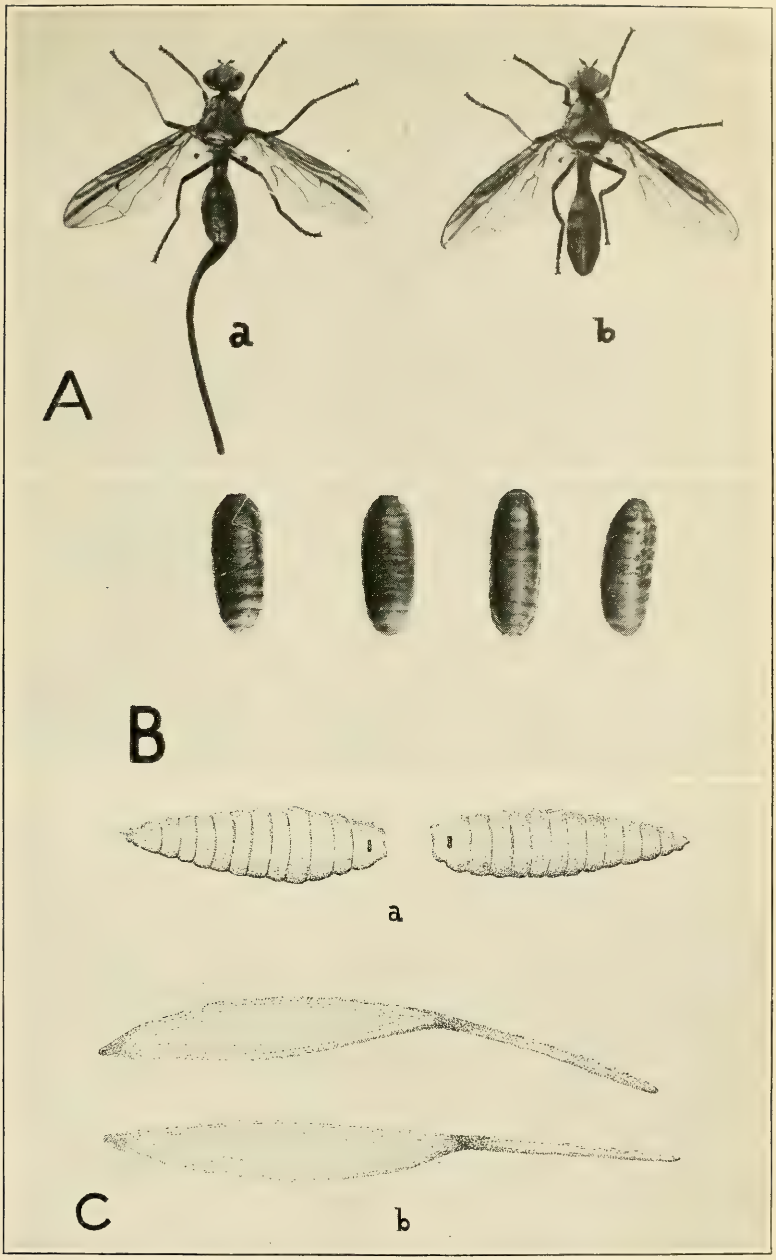
One hundred fresh puparia placed in soil in a jar and kept without any water being added. All died.

One hundred fresh puparia placed in soil in a jar and kept moderately moist; 80 adults emerged, 20 died.

One hundred fresh puparia placed in soil in a jar and kept wet every day. All died.

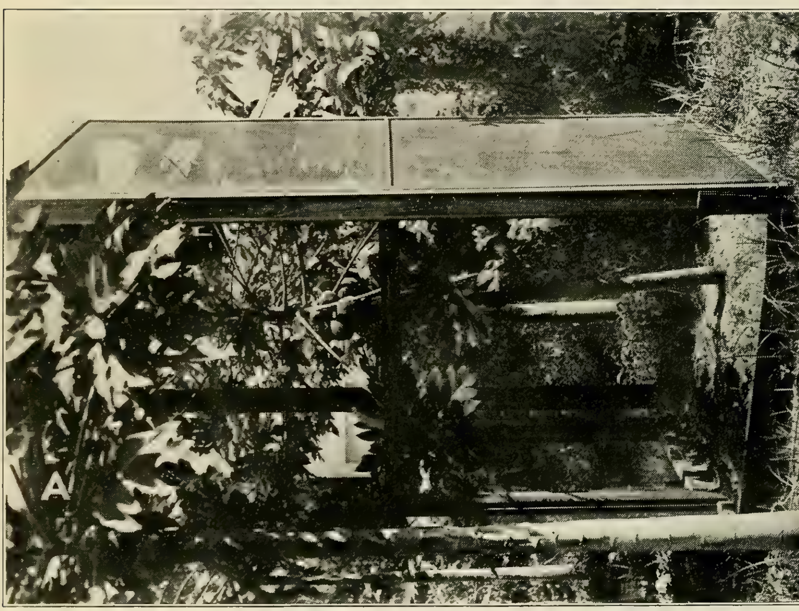
Even under the most favorable conditions of heat and moisture the puparia do not all mature, and 70 per cent is a very good average. Under natural conditions the average runs below that. Sev-

[4] Hooker, C. W. Fruit flies. In Porto Rico Agr. Exp. Sta. Ann. Rpt. 1912, p. 36. 1913.



TOXOTRYPANA CURVICAUDA.

A, Adult flies: *a*, Female; *b*, male. × 2. B, Puparia. × 1½. C, *a*, Larvæ, × 2; *b*, eggs, × 20



TOXOTRYPANA CURVICAUDA.

At left, type of cage used for rearing papaya fruit flies in fruits on the tree. At right, papaya fruits after being stung, showing characteristic exudate of milky fluid caused by the females puncturing the skin. (Photo by G. F. Moznette.)

eral hundred puparia placed in jars, some of them reared from larvæ and others gathered in the soil under trees, gave results as shown in Table I.

TABLE I.—*Males and females of Toxotrypana curvicauda maturing from puparia placed in jars.*

Number of pupæ.	Number of males.	Number of females.	Total emerged.	Total died.
870	279	281	560	310

Thus it is seen that only 64.3 per cent matured into adults, while 35.7 per cent died. Of the number maturing practically 50 per cent were males and 50 per cent females.

Practically all the adults emerge from the soil in early morning just before daylight. Very rarely will one emerge between sunrise and midnight. The adults often carry the pupal case to the surface of the ground before freeing themselves from it. Only a few minutes are then required for their complete development.

ADULT.[5]

The adult of this species (Pl. I, A) is a wasplike fly, very much resembling in coloration and general appearance the wasps of the genus Polistes. The body is yellow and brown, marked with black, and the females are made strikingly conspicuous by a long, curved ovipositor, even longer than the body itself. There is considerable variation in the size of the flies, but they average about 12 mm. in length. The ovipositor of the female varies from 10 to 14 mm. in length.

The flies exhibit a rather rapid flight and walk with a quick nervous motion. The females are not often seen on bright days but appear about the trees to lay their eggs in the late afternoon or evening. They show a negative reaction to sunlight and always seek the shady side of the tree or fruit. Although sometimes seen during the morning and noon hours, the greatest flight occurs about an hour before sunset. The males, however, are more active on bright days. Both sexes are easily disturbed when resting on the fruits.

The life of the adult flies is probably only a few days in length. They have been kept alive in captivity for 31 days when properly fed, although the average is very much less. The flies will eat any kind of sugar sirup and the pulp and juices of some fruits, but they never appear to be attracted by any food. Many will die without

[5] For original description see Gerstaecker, A. Beschreibung einiger ausgezeichneten neuen Dipteren aus der familie Muscariae. In Ent. Zeitung Stettin, Jahrg. 21, No. 4/6, p. 194–195. 1860.

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ever eating when food is placed at their disposal. Others will eat only when food is placed directly in front of them or when they happen to walk into it. When they have once tasted the sweets they will feed until the body is well distended. The best results were obtained by placing drops of brown-sugar sirup on the net or screen covering of the cages. In the large cages it was sprayed with an atomizer on the under side of the leaves of the tree. The flies have a liking for the pulp of ripe papayas and also eat bananas but will not eat the juice of oranges.

The following figures show the length of life of some of the flies:

Fifty-four flies confined without food after emerging lived from 1.5 to 5.5 days, with an average of 3.45 days.

Thirty-six flies given water only lived from 3 to 6 days with an average of 4.6 days.

Seventy-six flies fed on sugar sirup lived from 3 to 31 days with an average of 7.4 days.

Under natural conditions these figures probably do not vary much. Five to seven days represent an average life for the adult.

COPULATION.

The insects copulate usually on the leaves or fruits of the papayas, but can only rarely be observed. Copulation takes place during the daytime, for the male is more active then, as noted above. He seems to experience some difficulty in holding the female in position because of the long ovipositor. To accomplish his object, he alights on top of the female and, clasping her body with the first two pairs of legs, he draws the ovipositor back and up with the remaining pair. Then by practically standing on his head he is able to bring the tip of his abdomen in conjunction with the end of the ovipositor. They usually hold this position for several minutes or longer, one pair being observed to remain for nearly two hours. If disturbed the female will walk around the fruit or even fly to another tree, always carrying the male along in position. In captivity the flies very seldom copulate. This is true when confined in the large cages over the trees (Pl. II, at left) as well as in small cages or jars in the laboratory. Of several hundred adults bred out in jars and observed at all hours of day and night, only a very few ever made any attempts at copulation. These cases happened when the flies were 4 or 5 days old and had been fed on sugar sirup or fruit pulp. If given no food they soon die without mating.

OVIPOSITION.

Oviposition usually takes place in the evening, that being the time the adult females are most active. It has been observed occasionally, however, to take place at all other times of the day. The fruits selected by the females in which to lay their eggs are

usually medium or larger sized, if all sizes are present on the plant. They often begin work on a plant when the fruits have just set and are very small, and all sizes of fruits are subject to attack. They seem, however, to prefer the half-grown or larger fruits, perhaps due to a natural instinct, for if the eggs are deposited in a nearly mature fruit, the fruit may ripen and decay before the maggots have completed their growth. On the other hand, if placed in very small fruits the maggots will mature before the fruit has started to ripen, and they sometimes experience difficulty in escaping from green fruits. It has been said that the milky juice from the green fruits is fatal to the larvæ, but this has not been found to be true. In fact, maggots which had been rolled around in the juice from green fruits completed their development.

It is not often that an adult fly will oviposit in a fruit where eggs or maggots are already present, although in a few instances maggots of two distinct sizes were found. When the first ones to mature escape they cause the fruit to decay, so the younger ones may not be able to complete their development.

The adult fly alights on the fruit selected and usually walks around for a time with a nervous motion. When she has found a suitable place she forces her ovipositor through the skin and flesh of the fruit and deposits her eggs inside in the seed cavity. This is accomplished by raising the long ovipositor up in a curved position and placing the tip of it on the fruit near the end of the abdomen, then forcing it through the fruit. The position taken is much the same as that of the ichneumon flies in depositing their eggs.

The eggs are laid in clusters and ordinarily only one cluster will be placed in a single fruit, although occasionally two or three are found. The fly often stings a fruit several times, as many as 10 punctures being counted at times, but does not always deposit a cluster of eggs. Possibly she is not able to reach through the flesh of the fruit in all places and hence withdraws and seeks a new place. In fact, many fruits are stung several times and no eggs laid in them. This has often happened in the breeding cages where fruits supposedly containing eggs failed to develop any maggots. Also many fruits on the trees have been marked after being stung and no larvæ ever appeared in them. Usually about two minutes are required by the female to deposit the eggs, although instances have been noted where the ovipositor remained inserted for an hour or more. Occasionally a female will become trapped and die in the milky juice which wells up when the skin is punctured. This exudate coagulates and holds the fly if she does not soon escape. Whenever a fruit is stung the exudate produces a characteristic mark by running down the side of the fruit and also coagulating in a large

drop at the puncture. (Pl. II, at right.) It is possible thereby to determine easily the number and location of the punctures.

SEASONAL HISTORY AND OCCURRENCE.

The insects breed throughout the year in Florida and are present in all stages at any month of the year. They have, however, some seasonal preferences and occur in much larger numbers at some seasons than others. The time of greatest flight of the adults seems to be during March and April, while in late summer and fall there are very few of them in evidence. This is correlated largely with the growth of the host plants, which begin fruiting usually in the fall and continue through the winter and spring. Many of the plants die down or are cut out in the late spring and new ones set. The flies therefore appear on the new fruits in the fall and continue to breed in increasing numbers throughout the winter and spring. The wild papayas in the hammocks fruit at all seasons and always serve as hosts whether or not any of the cultivated sorts are available. The generations are by no means marked and vary in length from 40 days in summer to 70 or more in colder weather. In a year's time there are about six generations, although they overlap and are in no way distinct. Moisture in the soil is a very important regulating factor in the length of all stages, perhaps even more so than changes of temperature.

POWER OF FLIGHT.

The distance which the adults are able to travel is not very great, for they are not strong fliers. One planting of papayas under observation was placed 2 miles from where any other plants existed and remained free from infestation throughout the season, the adults apparently being unable to cover that distance. In most locations, however, there are wild papayas all through the surrounding hammocks, and these serve to harbor and spread them.

SUSCEPTIBILITY OF VARIETIES.

While no distinct varieties of the papaya (*Carica papaya*) are recognized, there are several types of the fruit grown in the State. Several have been introduced from foreign countries and crossed on existing types. Then there are the original wild plants which have been cross-pollinated on the cultivated plants through natural agencies. Through all this cross-pollination there result two rather distinct types of fruits, one the small, round, or oval type with rather thin skin and flesh and the other the large, oblong fruits which usually have thick flesh. One especially fine fruit of the latter type has been produced at the Plant Introduction Gardens at Miami, Fla.,

by Mr. Edward Simmonds, and is known as No. 28533. These oblong fruits are much more immune to the attacks of the flies, due largely to the fact that the female flies are unable to reach through the flesh of the fruit with their ovipositors and lay their eggs. In fact, in some places they were found practically free from infestation and are considered immune by the growers. An examination of about 300 fruits of all kinds on the Florida Keys, by A. L. Swanson, an inspector of the State Plant Board of Florida, showed 90 per cent of infestation in the small round fruits as compared to no infestation in the large oblong fruits. This latter fact has not held good, however, in investigations by the writer. Several hundred fruits examined both on the keys and in many places on the mainland showed about 88 per cent of the round or oval fruits infested and about 15 per cent of the oblong fruits infested. In wild fruits in the hammocks the infestation is close to 100 per cent. No papayas grown in the State are entirely immune from the attack of the flies.

ENEMIES.

Only two natural enemies have been noted on this insect, one the jumping spiders and the other the small red ants which sometimes prey upon the larvæ. The large black jumping spiders conceal themselves between the fruits on the tree and are then able to catch the flies when they alight near them. Doubtless they destroy many in this way. On a few occasions ants have been observed attacking the maggots in a fruit which had fallen to the ground. They enter through the exit hole of the first maggot to escape and can then destroy the remaining larvæ in the fruit. They represent a negligible factor, however, in the control of the pest.

Six hundred pupæ dug from the soil under the trees and bred out in jars failed to produce a single parasite. The insect is well protected from the attack of parasites through nearly the entire period of its life.

CONTROL MEASURES.

The most effective way of preventing injury from this pest is by bagging the trees or fruits. Either cheesecloth or mosquito netting can be tied over the trees or around the individual fruits, and the flies will not try to sting the fruits through it. However, this plan is hardly practicable on a large scale, since it requires considerable work and expense and, in many cases, changing the bags as the fruits grow larger.

The adults are readily killed by feeding them a poisoned sirup, the best results being obtained by using sodium arsenite or potassium arsenate dissolved in brown sugar sirup. When given this sirup the adult flies die very soon after feeding, and they eat it as readily

as the plain sirup. Very good killing results were also obtained by spraying this mixture with an atomizer on the under sides of the leaves of the trees in the large cages. Large numbers of flies were found dead on the ground within a couple of hours. These soluble poisons, however, burn the trees very severely and can not safely be used. Even at the rate of 1 pound to 50 gallons, which is as weak as can be effectively used, severe injury was noted. Insoluble arsenic compounds such as Paris green, arsenate of lead, arsenate of calcium, and arsenite of zinc do not damage the trees but are not effective. When the arsenic is mixed in the sirup the flies do not get enough to kill them.

The following plan if carried out thoroughly will very materially reduce the number of flies and make the growing of papayas practical and profitable: (1) Selection of good seed and production of fruits of oblong shape and thick flesh which will offer more or less immunity to attack; (2) conscientious destruction of the infested fruits on the trees early in the season and before the maggots escape into the ground; (3) destruction of all inferior plants and wild plants around the place which might serve to breed the pests.

If a planting is sufficiently isolated from other papayas the flies may be killed out by destroying all the plants in the spring, about April or May, and resetting new plants. These young plants will begin to fruit in the summer or early fall, but there will be a period of about 60 days when no fruits are present, which is long enough to starve out the flies. Along with this program should go the destruction of all wild plants in the hammocks for a radius of at least 2 miles. One large planting under observation was kept free from infestation for the entire winter by this method and a good crop of fruit obtained. The previous winter and spring the plants were badly infested, but the pests were entirely starved out during the summer. In most locations, however, a grower would not be sufficiently isolated to practice this method successfully unless the cooperation of his neighbors could be enlisted.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1082

Washington, D. C. ▼ October 19, 1922

THE PRODUCTION OF TULIP BULBS.

By David Griffiths, *Horticulturist, Office of Horticultural and Pomological Investigations, Bureau of Plant Industry.*

CONTENTS.

GOOD TULIPS can be grown in America at a profit. They have already been produced in sufficient quantities and for a period long enough to command respect.

The tulips already produced experimentally are as good as the best. They bed, they force, they produce, and they reproduce normally under American conditions. This, coupled with the prospect of a profit in the growing, should beget a new industry in America. This industry, however, it is believed, must develop slowly, for experience is necessary and is as slowly acquired in this as in any other horticultural venture. It is also probable that the industry will not be more than supplementary to the existing sources of supply for many years, for it is scarcely probable that it can do more than meet the increment of tulip-bulb consumption which is certain when our economic conditions and transportation facilities again become normal.

There is, however, no limit to the quantity of bulbs which it is possible to produce in the United States. We have climates that are unexcelled for the production of these stocks. We have regions with

an abundant moisture supply from October to June, and we have dry summers. We have fertile sands, inexhaustible loams, and deep friable silts, upon all of which tulips can be grown.

With the start which has already been made by the Department of Agriculture on Puget Sound, by three or four companies in southern Michigan, by an association in the Willamette Valley, by a company in northwestern California, another in the Norfolk (Va.) region, and a score more in a smaller way in many scattered localities, the prospective grower should have no difficulty in obtaining the information required to enable him to avoid the pitfalls and to take advantage of the essential elements of success. This bulletin furnishes some of the necessary information. It is based upon investigations made on Puget Sound at Bellingham, Wash., in two locations, the first on the shore of Bellingham Bay and the second 3 miles inland.

THE TULIP BULB.

The whole tulip plant at maturity is condensed into a gigantic bud, called a bulb (see Pl. I), not very different from an onion. In the tulip, however, there is a single, continuous, usually brown protective covering. On the front of the mature bulb is a groove marking the position of the flower stem of the previous season (Pl. I, Figs. 2 and 3), the base of which usually remains attached to the base of the bulb. A full-grown bulb which has not flowered has a long stout neck and no flower-stem groove. (Compare clumps in Pl. I, Fig. 4.) The long neck is the petiole or stem of a strong leaf (Pl. II, Figs. 2 and 3) produced the year before flowering. (Compare the two clumps in Pl. I, Fig. 4, with Pl. II, Figs. 2 and 3.)

The bulb is made up of concentric layers attached to a basal plate (stem), between which at certain points are found buds, some or all of which, when the bulb is planted, develop into new bulbs, which may vary in size from 3 to 14, or in rare cases 20 centimeters in circumference. Usually one, often two, and sometimes three bulbs of this cluster will flower the next year, but it is seldom that more than one will give a first-class bulb of merchantable quality. (See clumps in Pls. III to V.)

The bulb of the tulip, unlike that of the narcissus, is always the product of the current season's growth and is not more than one year of age. One or more bulbs (Pl. III) are formed each season from each bulb planted, the size, quality, and number of such increase being directly dependent upon the size, vigor, and quality of the bulb planted; the soil, climatic factors, fertility, tilth, freedom from weeds; the general care and condition of the planting; and the character and adaptability of the variety.

The bulb grower is dependent for his profit on the character of the large bulb of this cluster, and for the continuation of his business

upon the nature and abundance of the smaller increase, commonly referred to as "the propagation." His planting is composed essentially of the bulbs below the largest bulb in the cluster, together with the small bulbs of the previous year's planting which have not grown to merchantable size during the current season.

PREPARATION OF THE SOIL FOR TULIPS.

Tillage for tulips should be thorough and deep. Upon the Whatcom silt loams of the Bellingham Bay region, where the work has been carried on, the average depth of the soil is not more than 12 to 16 inches. Thus far no subsoiling has been done, but the land has been prepared as deeply as possible with an ordinary 14-inch, steel-beam walking plow, 10 inches being probably close to the depth of the best preparation. Greater depth would undoubtedly be desirable, but good crops can be grown with this character of preparation on land where the drainage is cared for either by contourage, natural slope, or porosity of subsoil.

The soil is put in as fine a tilth as possible by the use of harrow, disk, float, and pulverizer packer. An almost indispensable tool is the rolling-disk clod crusher and packer, which has been used very largely on both silt and sandy soils, on the former mainly to pulverize and on the latter to pack the soil so that the edges of the beds will hold when marked out.

The proper use of tillage and soil-packing machinery exhibits in the highest degree the skill and efficiency of the grower in putting the bulb fields in just the right state of fineness and compactness, not only for the best crop results but also for the best handling in the planting of the crop.

LAYING OUT LANDS FOR PLANTING.

It is needless to say that, as in all farming operations, bulb lands should be rectangular in outline wherever it is possible. If lands are heavy and therefore to be bedded up, they have been roughly outlined by the tillage implements and are ready to have the ends of the beds marked. It is the practice to stretch a line on each side of the plat, the length of which is governed by the size of the field. The experimental plats were approximately 400 feet long. Along these taut lines a man proceeds with a 12 or 15 foot marker, on which are designated 36-inch and 12-inch spaces, alternating. With this he marks out the corners of the beds and drives stakes in each corner. If the sides of the plat are parallel, or, in other words, if the plat is of uniform width and the first stakes on each side of the plat are set directly opposite each other, the beds are rectangular, and no difficulty will be experienced in the future work provided the measurements are accurate. It is well to exercise much care in setting the

first stakes, even to laying out the first corners with a square, for future operations are facilitated by accuracy in these initial preparations.

When the corners of the beds have been marked by stakes, the beds are marked off. This is done by first stretching a taut line on each side of the bed, guided by the previously driven stakes. Two men usually work at this job and open up a number of beds in advance of planting. Each man handles one end of the two lines. When they have been fastened, one man marks one and the other the other side of the bed, being guided by the taut line (see right of Pl. VI, Fig. 2). They drive the spade into the ground vertically 2 to 3 inches and pull the dirt toward the center of the bed with a sort of scraping motion. When each has marked his side, they are at opposite sides of the plat ready to take up the lines and transfer them to the next bed and continue the work in this way to the end of the plat.

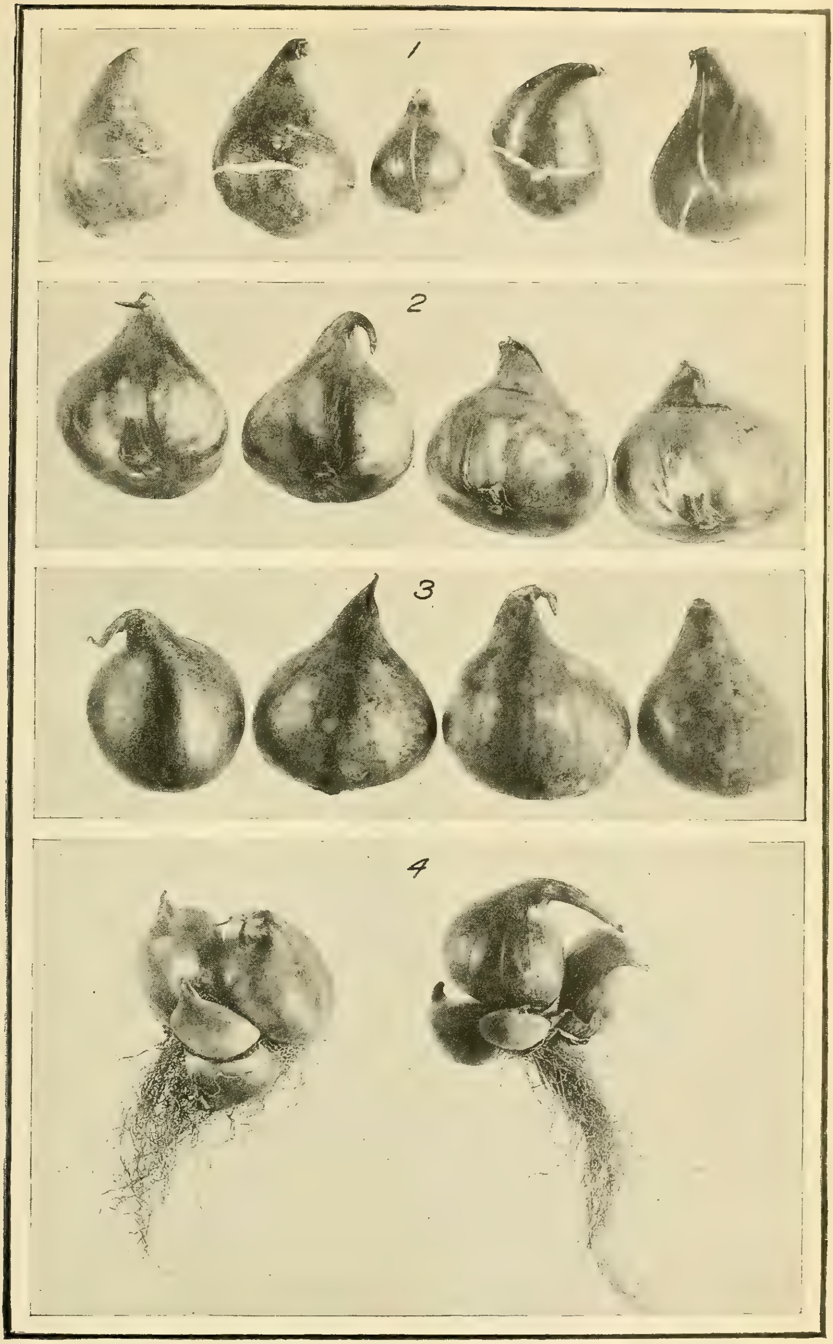
The width of the plat is the length of the bulb bed. The length of the bed is arranged purely as a matter of convenience in handling the bulbs in digging and planting.

PLANTING TULIPS.

The process of setting the bulbs in the ground is not essentially different for a great variety of bulbs. After the beds are marked off preparation for planting begins. All the soil to a depth of about 4 inches is thrown out of the first bed. The bottom is raked to a uniform level and fined with a garden rake. A roller marker is next run over the bed thus prepared. (Pl. VI, Fig. 1.) As soon as a space of 4 or 5 feet in the bed has been set with bulbs, the man with the shovel begins to open up the second bed by taking out the soil to a depth of about 4 inches, as before, and using it to cover the bulbs in the first bed; in other words, the soil taken out in opening a bed is used to cover the bulbs in the previous bed all the way across the plat. With experienced bulb men the marker is unnecessary, for they are able to set the bulbs in the required geometrical design without guidance.

HOW THE BULBS ARE SET.

The method of setting the bulbs varies with the different sizes. With tulip bulbs above 9 centimeters in circumference or with those sizes which are set upright, it is considered advantageous to strew them along the bed from the containers in which they are brought to the field. One man on each side of the bed on his knees sets the bulbs, usually 9 or 11 to a 3-foot row. When planting small sizes, indeed when planting all sizes below about 8 centimeters or those not set upright, it is advantageous to have small boxes a foot square and about 3 inches deep to hold the bulbs, which are



McKINLEY, FARNCOMBE SANDERS, AND CLARA BUTT TULIP BULBS.

FIG. 1.—Flowering bulbs of McKinley, showing the coats just starting to split from overexposure to light and air. FIG. 2.—Flowering bulbs of Farncombe Sanders, showing front of the tulip bulb (side next the stem). FIG. 3.—Same as Figure 2, but showing back of the bulb. FIG. 4.—Bulbs of Darwin tulip Clara Butt, showing bulb which flowered this year (left) and one which did not (right), the former planted 14 and the latter 21 to the row.

SINGLE EARLY TULIPS.

FIG. 1.—White Swan, showing the aboveground parts of three flowering plants. FIG. 2.—Keizerkroon, showing the aboveground parts of a plant whose bulb is too small to flower this year but which will flower the next season. Note the single very large leaf. FIG. 3.—Cardinal's Hat, a complete plant of a nonflowering-sized bulb which will grow to flowering size this year. Note as in Figure 2 that the single leaf is comparatively large.

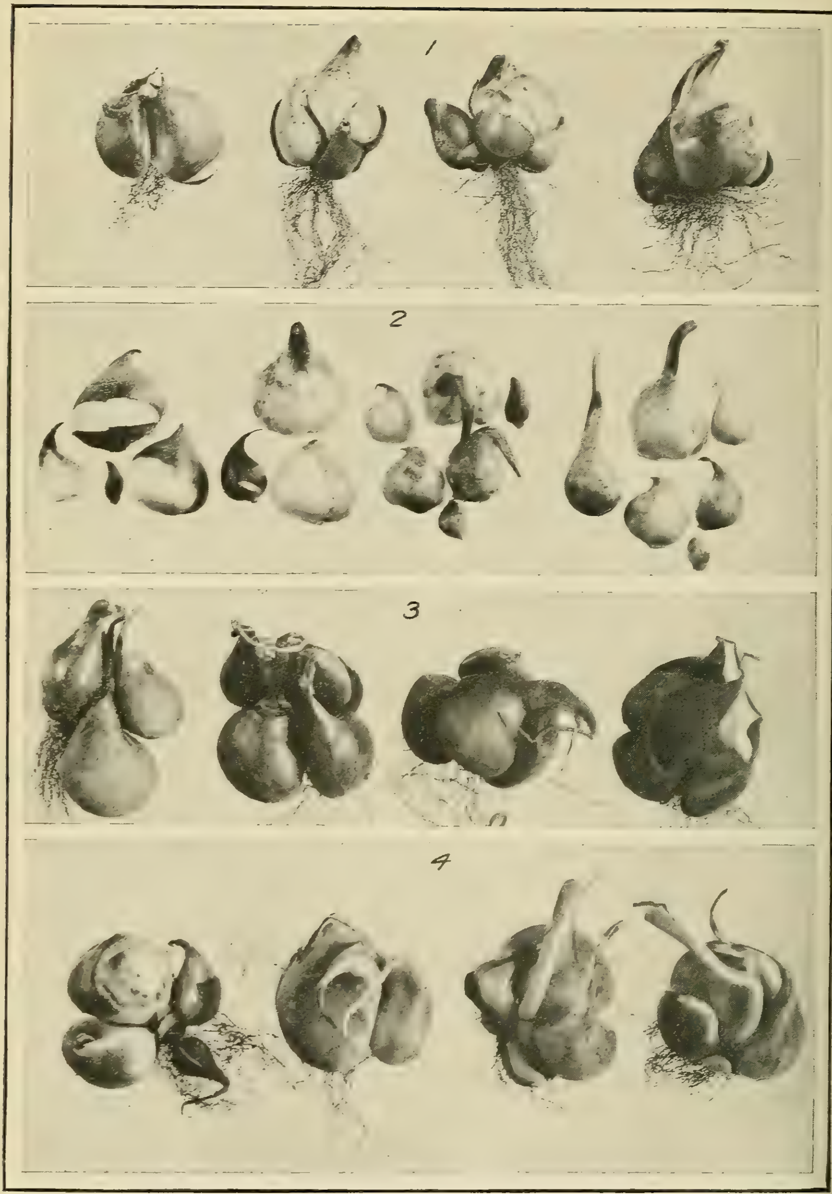
FIG. 1.—FIVE CLUMPS OF AXIMENSIS TULIP BULBS GROWN FROM 8-CENTIMETER BULBS.

Note that all have flowered and that there is a preponderance of long necks even in the increase. The bulbs have grown to 10 centimeters and have produced two 9, two 8, seven 6, eight 5, five 4, and three 3 centimeter bulbs in the increase. Besides the mother bulbs, at least four more will blossom next year.

FIG. 2.—FIVE CLUMPS OF MACROSPHILA TULIP BULBS.

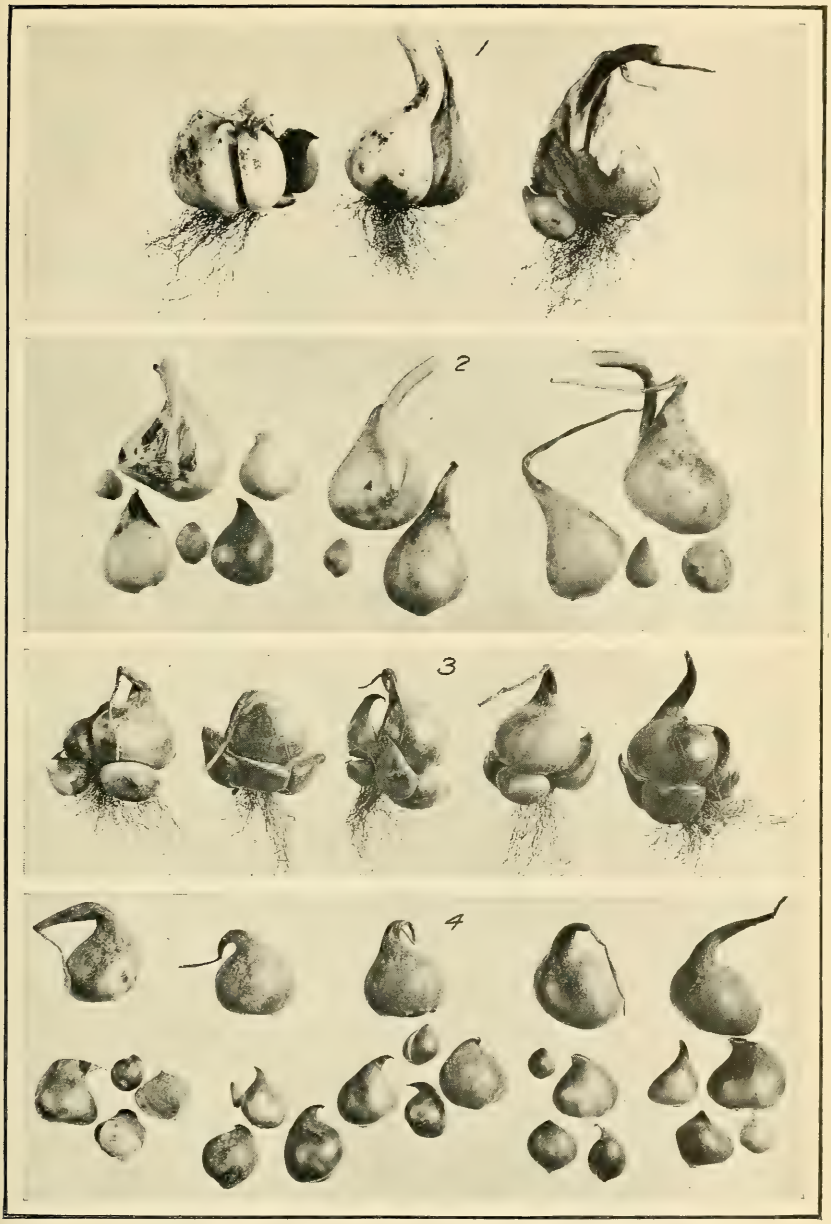
These were dug at the end of two years from 7-centimeter bulbs set 21 to the row. There are now five 12, seven 8, four 7, seven 6, five 5, and four 4 centimeter bulbs. Note the large masses of roots and preponderance of old coats.

SINGLE LATE TULIP BULBS



ARTUS AND ROSALIND TULIP BULBS.

FIG. 1.—Four clumps of the single early tulip Artus. The bulbs planted were 8 to 9 centimeters and set 14 to the row. FIG. 2.—The same as Figure 1, with bulbs cleaned and separated. Only the one on the left blossomed, but all have reached flowering size and each clump has produced two bulbs which will flower next year. FIG. 3.—Four clumps of the single late tulip Rosalind from 8 to 9 centimeter bulbs set 14 to the row. None have flowered. Note that more than one bulb in a clump has a long neck, indicating that each bulb planted produced more than one strong basal leaf which insures added vigor. This characteristic is seldom seen in the single earlies or Darwins. FIG. 4.—Four clumps of the same variety as Figure 3 and planted the same, but these have flowered. Note the long necks on two of the increase in each clump.



THE SULTAN AND CLARA BUTT DARWIN TULIP BULBS.

FIG. 1.—Three bulbs of the Sultan in clumps as dug. These were planted as 7-centimeter bulbs; all have flowered and reached mature size. FIG. 2.—The same as Figure 1, with the bulbs cleaned. Note the flower stems on each bulb planted; in each group are two bulbs which will flower next year. FIG. 3.—Five clumps of Clara Butt as dug, with some of the old hulls pulled off. The bulbs planted were 7 centimeters in size, set 21 to the row. Note the character and arrangement of the reproduction. FIG. 4.—Same as Figure 3, with clumps cleaned and separated. Note that although these have reached mature size, none of them flowered this year. Each 7-centimeter bulb planted has become 12 to 13 centimeters in circumference and produced another which will reach flowering size in another year, although all may not flower. This variety has an appealing flower and is a good reproducer, two characteristics which make for commercial quality.

FIG. 1.—THE MARKER IN OPERATION.

FIG. 2.—THE OPERATION OF PLANTING TULIP BULBS.

The two men on the right are marking off a bed. One operation is not shown, i. e., covering the bulbs. The soil from the next bed on the right is transferred to cover the bulbs which the boys are setting.

PLANTING TULIPS.

placed from these containers. Sometimes, however, those planted 14 to the row are also strewn along the bed and placed from there. (Pl. VI, Fig. 2.)

Bulb setting, while appearing simple, is a job requiring a great deal of dexterity. Boys commonly succeed better at it than men, and some boys are able to place twice as many bulbs as others.

With a crew of two men to shovel and rake, it is desirable to employ two to four boys to place the bulbs. However, two capable boys and two men make an ideal planting crew.

In the mucking,[1] as in all else in this work, a regular system is followed. Three shovelfuls across the bed, provided the soil is in good tilth and hangs together well, remove sufficient soil to get the required depth. The mucker generally takes a shovelful from the right side, another from the left, and then one from the middle. This method is continued clear across the bed.

Usually in the soils used in the Bureau of Plant Industry experiments the man who rakes down the beds follows and throws out a small shovelful of earth from each edge of the bed. He works in the partially opened bed and faces in the opposite direction from the regular mucker, doing this work and keeping tally. One of the boys who is planting keeps a record of the number of rows by setting a stake. He calls off the numbers of the rows and of the bulbs planted to the row, which the raker jots down in his planting book each time a change of size is made. This record is simply a skeleton, but with a little computation it gives the total number of bulbs planted and the number of each size. From this record the grower experienced in tulip production in any region may predict with considerable accuracy what can be turned off at the next digging. The row is one of the most useful units of record in bulb culture. Some record of this nature is considered desirable, if not absolutely necessary, not only in experimental but in commercial bulb growing also.

BULBS SET ACCORDING TO SIZE.

The bulbs are set according to size; the larger the size the fewer the bulbs set in the row, the principal thing being to get as nearly as practicable the same quantity of plant material in equivalent areas.

The practice adopted in the investigations of the Bureau of Plant Industry doubtless could be improved; but it is approximate, fits in fairly well with the facilities for sizing, and varies but little from true accuracy. At present, with the fertility of cover crops on virgin soil, no fewer than 11 bulbs are planted to a 36-inch row. All bulbs larger than 10 centimeters are given this spacing and are set upright. The next size for planting is caught by the 8-centimeter sieve. These bulbs are planted 14 to the row. The bulbs caught in the 7-

[1] The shoveling.

centimeter sieve are planted 21 to the row, and the 5-centimeter bulbs are planted 35 to the row. All bulbs which pass a 5-centimeter sieve are strewn along, about 50 to the row. The fourteens, twenty-ones, and thirty-fives are planted in 7 clusters of 2, 3, and 5, respectively.

THE PLANTING RECORD.

The record made at planting time furnishes the basis for all computations on the grower's inventory. In bulb culture the grower is constantly dealing in large numbers. At present we are putting little short of 350,000 bulbs on an acre. It is desirable to have a reasonably accurate estimate of these without the labor of actually counting them. This is accomplished by getting a count of the number of rows of each size planted. To accomplish this, one of the boys who sets bulbs keeps the tally and when a change of size is made calls the number of rows of each size planted to the foreman of the planting crew, who jots down the number in the proper space in a notebook previously ruled. The form of this record is shown in Table 1.

TABLE 1.—*Form of the planting record.*

Inventory No.	Name of variety.	Number of rows planted of each size.				
		11 to row, above 10 cm.	14 to row, size 8 cm.	21 to row, size 7 cm.	35 to row, size 5 cm.	50 to row, size under 5 cm.
479	*Artus*	*75*				
490	*Couleur Cramoisi*		*162*	*82*	*86*	
493	*Duchess de Parma*	*151*	*64*	*23*	*32*	
327	*Faust.*	*5*	*13*	*8*	*8*	*12*
334	*General Köhler*	*29*	*10*	*7*	*4*	*5*
231	*Jassi Prince William*	*19*	*8*	*6*	*4*	*2*
617	*Kaufmanniana*		*2*	*1*	*3*	
526	*McKinley*	*327*	*184*	*102*	*90*	*104*
410	*Professor Trelease*	*22*				
418	*Rev. H. Ewbank*	*45*	*13*	*10*	*4*	*5*
538	*White Swan*	*163*	*62*	*109*	*64*	*95*

Adding the horizontal column gives the total number of rows planted to any one variety. This can also be obtained by multiplying the number of running feet of a 3-foot bed by 2, since the rows are 6 inches apart. To arrive at the number of bulbs of any size planted, the figure representing the number of rows must be multi-

plied by the figure at the head of the column. The total number of bulbs of any one variety planted is the sum of the product of the number of rows of each size multiplied by the number of bulbs planted to the row in each size.

SIZES AND QUALITY OF BULBS USED FOR PLANTING.

The quality of one's planting stock can not be designated in centimeters any more than by any other known standard of measure. There are so many factors entering into consideration as to make the grower's planting stock the most variable element in the production of tulip bulbs. There is one idea which the producer should always have in mind, i. e., he should strive to set for the next season's turn-off as large a percentage of sizes which will mature in one year as is compatible with the production of sufficient planting stock of the same character for the succeeding year. In other words, it is the smallest planting bulbs which will grow to maturity in one year, which are set and dug but once, that will yield the greatest net cash returns, and it should be the grower's aim to use in his planting as large a percentage of such bulbs as possible.

When any stock is scarce or hard to get and it is desirable to increase the planting, the grower may find it to his advantage to plant every bulblet he has, in which case his planting bulbs may vary from 3 to 14 centimeters or more in size. In the general run of the business, however, bulbs below 5 centimeters in size should be discarded, because the length of time it takes to bring them to maturity cuts down the profits too much. Practically all bulbs of 5 to 7 centimeters, under good cultural conditions, should reach merchantable size the second year, and those 8 centimeters and over should reach maturity in one year.

Often the commercial grower reserves his toppers [2] and plants them. It is from these that he gets his greatest proportion of increase. But there is as much psychology in this practice as there is in selection. The grower can not afford to turn off the small percentage of oversized bulbs to the consumer, who may be ignorant as to what the size of the bulbs should really be and is likely to gauge the quality of his receipts by the quality of the small percentage of top-sized bulbs. These toppers, on the other hand, while giving a merchantable bulb the next season, together with a numerous progeny, are expensive to grow, for the reason that they are large and require a greater space than the smaller bulbs which are just large enough to come to maturity in one year and be turned off.

The proper size to plant in order to obtain a mature bulb at the next digging is dependent directly on the fertility of the soil and inversely on the thickness of the planting.

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[2] The largest bulbs of a variety.

The grower, of course, will be governed in his planting by the stock which he has on hand. If his turn-off of bulbs has been close, his planting stock will be proportionally reduced in size. It will take a little time for him to determine just where the dividing line lies between his merchantable stock and a sufficiency of advantageous sizes for planting.

DISTRIBUTION OF PLANTING MATERIAL.

As stated on another page, the object of the close sizing of planting stock is to get an even distribution of plant material over the ground. The sizing in the experimental work considered here has been an approximation, possibly closer than will obtain in commercial planting, but by no means exact.

In order to test the closeness of the approximation the following tabulation was made at the time of planting in 1919. The variety used was Artus.

1 bushel of bulbs under 5 centimeters planted 50 to a row covered 137 rows.
1 bushel of bulbs of 5 centimeters planted 35 to a row covered 119 rows.
1 bushel of bulbs of 7 centimeters planted 21 to a row covered 129 rows.
1 bushel of bulbs of 8 centimeters planted 14 to a row covered 135 rows.

The test was made in the field at planting time with the stock as sized in the bulb house. Exact comparability would require that 1 bushel of bulbs should plant the same number of rows of all sizes. Of course, perfect uniformity with such inequalities in the sizes employed can not be attained.

ADVANTAGES AND DISADVANTAGES OF THE BED SYSTEM OF PLANTING.

In the United States there is always an effort to eliminate as far as possible hand labor in all farming operations. We perform by machinery many operations which the foreigner finds it cheaper to do by hand. One of the stock arguments against the bulb business in the United States has been the expense entailed by the very large proportion of hand labor required. The bed system means hand labor. (Pl. VI, Fig. 2.) Whether the bulb business in this country can be divorced from it remains to be determined. It is not the purpose of this bulletin to decide which is the better way, but simply to show that bulbs have been produced in this country, to tell how the growing has been done, and to point out the fundamental operations involved in their production. To determine whether there is a method superior to the bed system will require much experiment, and the question may not be settled for years; indeed, it would not be well to try to establish at this time any degree of finality in methods.

In the use of the bed system a maximum quantity of material can be grown on a given area. The production of bulbs as practiced

under this system is one of the most intensive of horticultural practices, and there is a decided advantage in thick and exhaustive cropping. The land over the whole bed is fully occupied by the plants, and there is a minimum of vacant area in the paths between the beds, probably not more than 6 or 8 inches of unoccupied soil in the 4 feet needed by the work incident to culture and handling.

In the production of tulip bulbs, to a greater degree than with the narcissus, gladiolus, and many other bulbous stocks, care in handling the plants is a very important factor. The main advantage of a row system of planting is to allow the use of some implement for keeping down weeds and cultivating, but in tulip culture the use of even a wheel hoe close enough to obviate the necessity of hand weeding is likely to prove detrimental. The leaves are stiff, rigid, in the way of tools, and easily bruised, and mechanical injury of any kind to the growing plant is conducive to the development of the fire-disease organism which, together with the loss incident to a thin planting on heavily fertilized soil, would at least go a long way toward offsetting the advantage gained in handling the crop on a cultivated-row basis.

The bed method of planting, if well done, has a decided advantage in that the bulbs are more easily set at a uniform depth. They are planted in a geometrical design, and each can be found without surface indications when the first row in the bed is located. These are very important considerations in a crop in which uniformity of growth and delicacy of handling are demanded.

The advantage of row planting with implement cultivation has not yet been made clear. Implements can not well be operated closer than 3 inches to a row of tulips. This necessitates the hand weeding of 3 inches on each side of the row. In beds the rows are 6 inches apart. It appears from this that the hand labor for a given length of row is identical whether the planting is 6 inches or 2 feet apart, and the closer planted bed holds three or four times as many bulbs as the other per unit of area. Some employ a bed 8 to 10 inches wide with about a 16-inch space between.

With these few observations, the question as to which method is best is left open, with the statement that so far as experience goes the production of tulip bulbs adapts itself to the intensive rather than the extensive method of culture.

For the present the subject of planting or digging tulips by machinery may be dismissed. No machinerv for either of these operations has yet been invented.

WHEN TO PLANT TULIPS.

The best time to plant tulips is before the middle of September, but through October is all right. The main objects of digging the bulbs

each year are to renew the fertility of the soil, to separate the merchantable bulbs from the others, and to distribute and rearrange the remaining bulbs in order to prevent crowding. These things accomplished, the bulbs are better off in the ground than in any storage that can be given them.

The practice of the Department of Agriculture has varied. In some years planting has not been completed before December, but for the past three years the digging has been mainly done in July and the planting in August. Early planting is to be preferred.

On the other hand, the tulip bulb is very adaptable and may be planted with a degree of success as late as the ground can be worked. Indeed, the bulbs may often be carried over winter in storage, planted in early spring, and the stock saved.

In practice the grower will begin planting as soon as he has finished digging and cleaning. The exact time of starting and finishing each operation will depend upon the season, the amount of digging to be done, the labor available, and other factors that enter into the economy of farm operations.

TREATMENT OF THE BEDS AFTER PLANTING.

The surface soil of the planted bed is left as it is dropped from the shovel until the planting is done. It is soon settled naturally by a shower of rain. Late in the season, or as soon as weeds begin to grow, cultivation begins and is continued, to kill successive crops of weeds and smooth off the surface, until winter sets in and prevents further work on the ground. In tulip culture, economy requires a maximum of cultivation before the plants appear above ground and a minimum afterwards.

This cultivation in autumn is done in various ways. The most expeditious method is with a wheel hoe which is operated with weeder knives attached, usually across the beds. Commonly this is the only tool used.

After two or three weeks there need be no hesitancy in walking over the beds enough to do this cultivating, but immediately after planting the beds should be walked on as little as possible and no more than is necessary at any season.

MULCHING.

The most approved practice requires clean culture for tulips. The one objection to a mulch on tulips is the danger of the spread of the fire disease caused by the fungus Botrytis, which may be very destructive wherever the conditions are such that both the surface of the ground and the plants are continuously wet for days at a time.

Since tulips are grown mostly in regions where low temperatures and humid conditions obtain during the growing season, it will be much safer for the grower to practice clean culture.

SPRING CULTIVATION.

In tulip culture tillage of the soil with implements after the plants are above ground is not generally considered practicable. In the present location of the tulip experiments of the Bureau of Plant Industry it has been scarcely possible, on most of the soils, to do any cultivation after winter sets in until about the time the early varieties are done blossoming. In spring, therefore, cultivation has not gone beyond keeping the paths free of weeds with a wheel hoe and weeding the beds mostly by hand when weed growth was bad. One tool which meets with greater favor than any other with the men when work on the beds is imperative is a light hoe with a blade only 3 inches wide. With care this can be operated to remove the weeds between the bulb rows while standing in the paths. In reasonably clean soil the common 5-pronged hoelike cultivator can be used to good advantage when reduced to three teeth set to a spread of 2½ to 3 inches. This can be drawn between the rows to a depth of about 2 inches to very good purpose in aerating the soil which has been packed by the winter rains. In the experimental work, however, cultivation of the tulip beds in spring has not been generally practiced.

It is absolutely essential to good results that weeds be kept down. The work of weeding is amply compensated by the saving of labor at the time of harvest, to say nothing of preventing the accumulation of weed seed in the soil and the interference with the crop where weeds are bad.

Proper handling of the soil will reduce the weed nuisance to a minimum. With ground kept continuously well tilled and free from weeds through late-autumn cultivation of the beds, and with a good stand of vigorous tulips, weeds become a minor factor in tulip-bulb production. This experimental work is on new ground, and it is far from free of weeds. In spite of this, last year only 1½ man days were spent pulling weeds from the beds on an acre planting.

AGE OF FLOWERING BULBS.

The "age of flowering bulbs" is in reality a misnomer, but is used because so often heard in connection with the bulb business. All tulip bulbs, whether large or small, are in reality of the current year's production and therefore not over one year of age. The tulip produces a new bulb or bulbs each year just as truly as the gladiolus or freesia corms are renewed by an entirely new structure each season. (See Pls. III, IV, and V.) For this reason the flowering quality of

the bulbs is measured by size rather than by age. However, if bulblets below 5 centimeters in circumference be planted, it can be said with confidence that with most garden tulips some of these will blossom the second and the remainder the third year.

BLINDNESS.

A blind tulip is one which has reached flowering size and may or may not produce a stem, but does not flower. It may or may not have flowered the previous season. The causes of blindness in commercial bulbs are varied. It may be due to slight heating in the pack in transit, to too high a temperature at the time the plants are rooting,[3] or to improper temperature or moisture conditions at the time the bud is coming to view, to escaping gas, or in some sections to heavy infestations of plant lice.

It not infrequently happens that sufficient heating occurs in transit to kill the flower while the bulb is little if at all injured for growth. The only way to detect this defect is to cut a bulb open. A dead flower can easily be recognized. No case is known to the writer where bulbs of proper size and firmness have been grown with no flowers in them. The blindness has invariably been brought about by treatment after digging. When blindness occurs in bedding tulips the defect is most commonly traceable to heating somewhere in storage. When it occurs in forced stocks the trouble may be the same or it may be due to improper handling. It may be accepted as axiomatic that a tulip bulb of proper size and ordinary firmness has a flower in it and if properly handled will produce that flower.

RELATION OF SIZE OF BULB TO SIZE OF FLOWER.

In general the size of the flower in any variety is proportional to the size of the bulb. It takes a certain size of bulb to produce a flower, and the larger and more perfect the bulb the larger and better the flower. It is under conditions of starvation and crowding that flowers as well as bulbs become small, and some varieties will reduce the size of their flowers beyond anything to be thought of in other varieties. Lack of proper fertility over a period of years will often cause excessive splitting of bulbs. Poor fertility and neglect will also give much smaller flowers than will be found under conditions of careful cultivation, although all the progeny may be planted, from a 3-centimeter bulblet up.

Flowers of Artus under poor fertility may be not over three-fourths of an inch in diameter when fully opened, but in well-grown stocks the smallest flowers are never so small.

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[3] This applies to blindness under forcing conditions and also may apply to bedded tulips in the extreme South.

EARLY MATURITY AFFECTING THE BLOSSOMING SEASON.

It is very important for the grower to realize that the tulip bulb is not inactive during the so-called dormant period, when the bulbs are out of the ground. (Compare the bulbs in Pl. VII, Fig. 3.) Profound changes take place in the bulbs on the shelves, which though invisible, are no less important than the development of leaf stem and roots the next season. Upon these changes largely depends the time of flowering the next season. Consequently, with a varying dormant season there will be a corresponding variation in the next flowering season. But with given conditions during dormancy, the earlier the bulbs mature the earlier they will flower the next season. Besides, under our Puget Sound conditions, bulbs dug and kept on the shelves less than two months flower earlier than those left undug

It will readily be seen that stocks which mature early will blossom earlier the next season than those which mature later. A difference of a few degrees of temperature for two months during storage, however, will greatly advance the development of the flower spike and consequently cause the stocks to blossom earlier. This principle forms the basis of the early flowering of the Dutch Prepared bulbs which have been put on the market in recent years.

Some experiences with early-maturing stocks are to the point. Several varieties of single early tulips were salvaged from the beds on the grounds of the Department of Agriculture in April, 1919. They were heeled in to ripen, dug, and dried by June 15 in the climate of Washington, D. C. They were then shipped to Bellingham, Wash., and planted with the other stocks of the same varieties in August. The next spring these all flowered from a week to 10 days ahead of the home-grown Bellingham stocks. Indeed, Keizerkroon flowered so early that it was 10 days after it was in full flower before the petals could spread because of low temperatures. This is an extreme case, but illustrates well the effect on the next season's blossoming of early maturity coupled with high temperature at the time of curing.

In the purchase of stocks the tulip grower will find a great variation with the locality in which the stocks are grown, as well as with the condition under which they are handled during the so-called dormant period.

SALE OF FLOWERS.

The sale of flowers has little place in connection with tulip-bulb production. The production of flowers and of bulbs for sale are two separate ventures and are largely incompatible.

For the flowers to be of value they must have long stems. To secure these in any tulip requires the removal of leafage, which is not compatible with proper bulb production.

Some growers follow the practice of cutting the stems below the upper leaf, thus removing a minimum of the feeding surface of the plant; but even this interferes with the best production of bulbs. It is not good practice in bulb production, and tulip bulbs will gradually deteriorate under this treatment.

The practice may be conducted with less injurious effects with the Darwins and some other single late varieties than with other tulips, for the reason that when well grown these plants have a foot of stem above the top leaf. Cutting above this leaf can be safely indulged in, and the flowers will be decorative, provided greens from some other source be supplied.

REMOVING THE FLOWERS.

In the production of tulip bulbs it is imperative that no flowers be allowed to fall to pieces on the beds or any seed vessels allowed to mature on the plants.

The tulip stem is brittle, and a quick, abrupt bending of it between the thumb and forefinger will snap it off with certainty. (Pl. VIII, Fig. 1.) The operation should be performed before the flowers drop their petals, and all flowers and portions of flowers should be carried out of the bulb fields.

In regions best adapted to tulip culture the dropping of the petals on the foliage and on the surface of the ground during humid weather is fraught with danger. When this is allowed to take place, the decaying petals if they remain damp all day form the best kind of medium for the development of the fungus Botrytis, the cause of the fire disease. It is therefore the practice of bulb growers to remove all flowers of tulips before the petals begin to fall.

Preferably two men work together, one on each side of the bed, and snap off the flowers with an inch or two of stem, placing them in a pail or any convenient container, to be emptied into larger receptacles or carts in the roadways and later removed from the bulb fields.

In many regions where tulip bulbs can be successfully grown the danger from fire injury is reduced to a minimum if the general atmospheric conditions are such as to cause the petals to dry up rather than to decay on the plants or on the ground. Even under these conditions it is necessary to remove the flowers, for the reason that practically all tulips produce seed profusely, and when they are allowed to do so the production of bulbs is correspondingly reduced.

The time at which the flowers are removed may vary. It is customary to remove them after they have faded and before the petals fall. They can just as well be removed in the bud, but there is a certain advantage in public appreciation and local enjoyment

in leaving the flowers as long as they are in good condition. There is the further advantage to the grower that he is able to true up his stock.

WHEN TULIPS ARE RIPE.

Generally speaking, tulips are ready to dig as soon as the tops have dried down in June. The precise time when they should be lifted, however, will depend somewhat upon the variety and varies slightly with the season. In the single early varieties it is not necessary to wait until the tops are dry. When they have yellowed well and the upper leaf has dried, most of the varieties may be lifted. The color of the outer coats is a good criterion. The bulbs should be dug as soon as the outer coats have turned to the rich brown so characteristic of the tulip. The sooner they are dug after maturity the better the coats are preserved. As a rule, tulips should be lifted just as soon as possible after the proper time comes, and this is especially true of the single earlies and Darwins. The experience of the Bureau of Plant Industry with single late forms, such as the Gesnerianas and Picotees, is that they are sometimes not ready to dig for a week or more after the tops die down. Often the bulb coats are perfectly white at the time the tops dry. This is especially noticeable if the soil is poorly aerated. The one important consideration as regards the time of digging is to do the work at the time when the coats will be best preserved. This means digging early. It means digging as soon as the plants are far enough advanced for the coats to be perfectly formed and to assume their normal color upon drying. If digging is long delayed, the coats deteriorate and the bulbs lose this natural protective covering. Often bulbs go into the bulb house with half of the coats white. If the soils were sandy loam, the coats would form earlier and be stronger.

The moisture, heat, depth of planting, and nature of the soil all affect the maturity and coloration of the coats. With lack of moisture they dry off quickly and mature. Heat has about the same effect. In sandy soil the coats form and brown up better than in heavier loams. If the bulbs are planted shallow on heavier soils, the coats will brown up quicker and the plants be ready to dig earlier than when planted deeper.

DIGGING TULIPS.

Plate IX, Figure 1, gives a better idea of the operation of digging than a long description. The men work on their knees and take out the bulbs with a small short-handled spade. (Pl. X, Fig. 4.)

The operation of digging tulips and other bulbous stocks, while very simple, is one which is capable of being highly developed. The good digger is active, quick, and alert in his movements. He operates his digging tool with a positive movement. He fixes in

mind the planting scheme, which enables him to pick up the loosened bulbs and drop them in the tray with no lost motion.

The beds when ready to dig have been hoed off, and there is nothing to indicate the position of the bulbs. The first row in the bed may vary as much as 4 or 5 inches in its position. In starting to dig, therefore, it is necessary simply to find one bulb in the first row. This is done by scratching off the soil over 6 inches or more of the surface until the nose of a bulb or perchance the remains of some of the stems are seen. It is then a simple matter to dig behind the row straight across the bed and remove the bulbs.

The digger always keeps a furrowlike trench in front of him in the position of the last row dug. In starting on a new row he strikes back 6 inches with his spade. The bulbs are located in the middle of this 6-inch space. With a few short, sharp jabs with his spade he removes 2 to 3 inches of the upper layer of soil in a 6-inch strip across the bed. This invariably exposes some of the bulbs and visually demonstrates the exact position of the row. This operation of uncovering proceeds from right to left or from left to right across the bed. The digger then begins back on the right or left again. With another thrust of the spade and again pulling the dirt and bulbs toward him he loosens the bulbs for a 6 or 8 inch section of the row. The bulbs are then placed in the screen-bottomed trays and the rest of the row removed in the same way, and so on with the next row. In some cases, especially with large bulbs, the whole row of bulbs is loosened after being uncovered before any of the bulbs are picked up. These directions for digging appear more complicated than they really are. The operations are simple and quickly made.

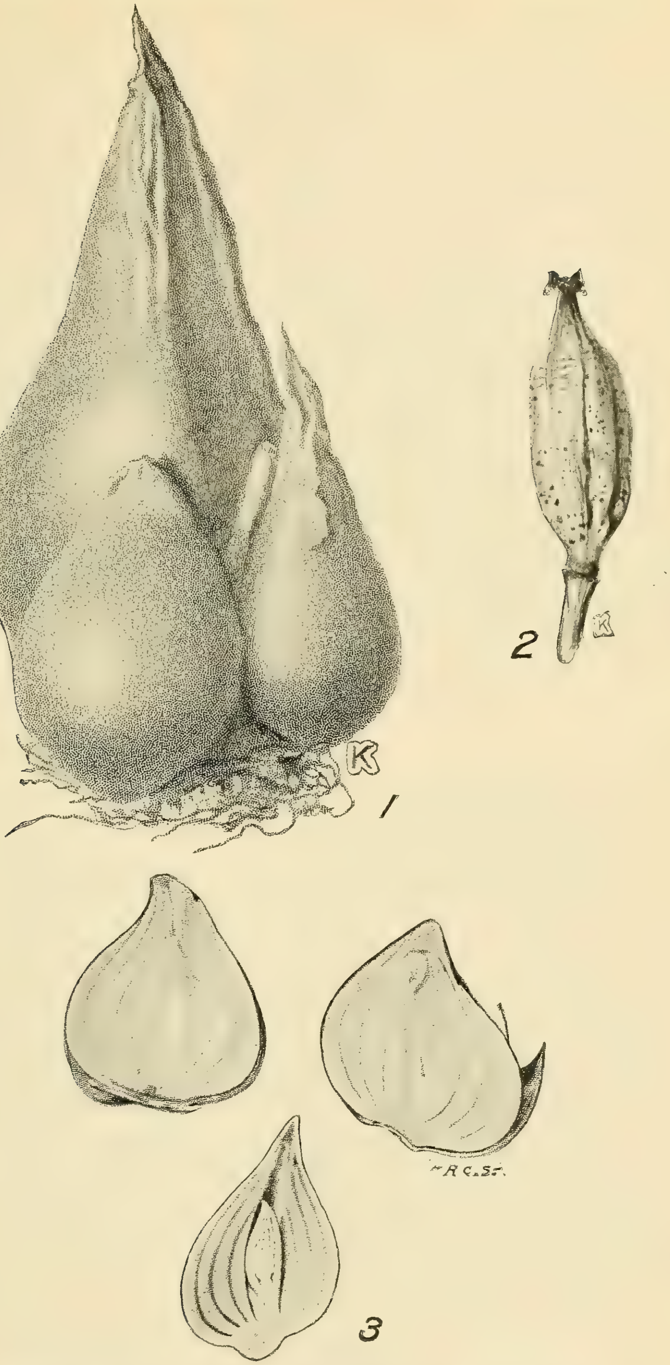
The uncovering of the row before loosening the bulbs seems to be advantageous on heavy soils, but on the lighter soils the loosening of the bulbs is accomplished with one movement of the digging tool.

The bulbs come out of the ground for the most part in clumps. The digger lifts the whole clump without any attempt to get it free from dirt and places it in the hand screens described elsewhere. These receptacles the digger pushes ahead of him over the bed as he digs. When the tray is two-thirds full, the contents are sifted lightly to remove the loose dirt and the bulbs poured into the lug boxes and taken to the bulb house.

In case the quantity of the variety being dug is large or the bulbs very damp, it is often advisable to employ a large shaker, like that shown in Plate IX, Figure 2. This is operated by two men, and about a bushel of bulbs is cleaned of loose dirt at one time.

IMPORTANCE OF CLEAN DIGGING.

Wherever bulb culture is taken up in earnest great care should be exercised to get all the bulbs out of the ground. Aside from the



GROWTH CONDITIONS AND FIRE-DISEASE OF TULIP BULBS.

FIG. 1.—Darwin tulip clump of bulbs with improperly filled coats due to bad cultural conditions. FIG. 2.—A dwarfed seed pod of single late tulip *retroflexa*, showing the resting stage (sclerotia) of the fire-disease fungus (Botrytis). FIG. 3.—Single early tulips in vertical section, showing (above) the absence of flower indications in July when the bulbs were dug and (below) the well-developed flower later in the season.

FIG. 1.—REMOVING FLOWERS FROM THE BEDS OF SINGLE EARLY TULIPS AS THEY FADE.

FIG. 2.—GENERAL VIEW OF A CREW CLEANING TULIP BULBS AROUND A LONG TABLE.

Cleaning the bulbs is usually a rainy-day job or a rush one between digging and planting time.

FIG. 1.—THE OPERATION OF TAKING THE BULBS OUT OF THE GROUND.

There are no surface indications, but the bulbs are in rows 6 inches apart. The digger is starting after the next row.

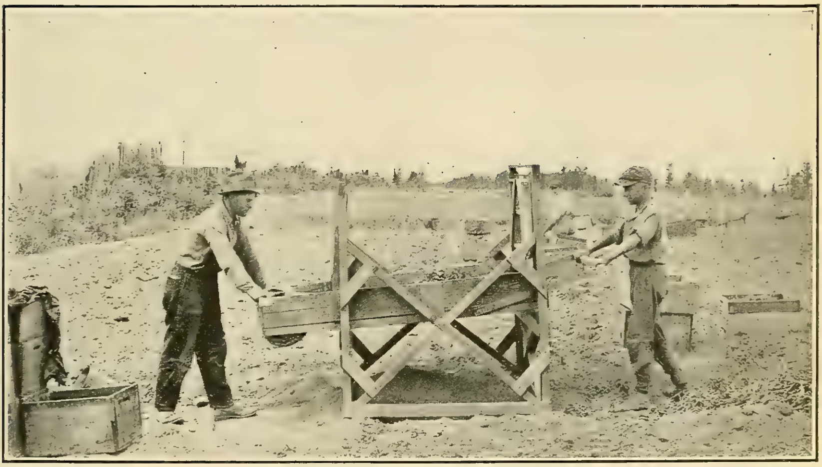
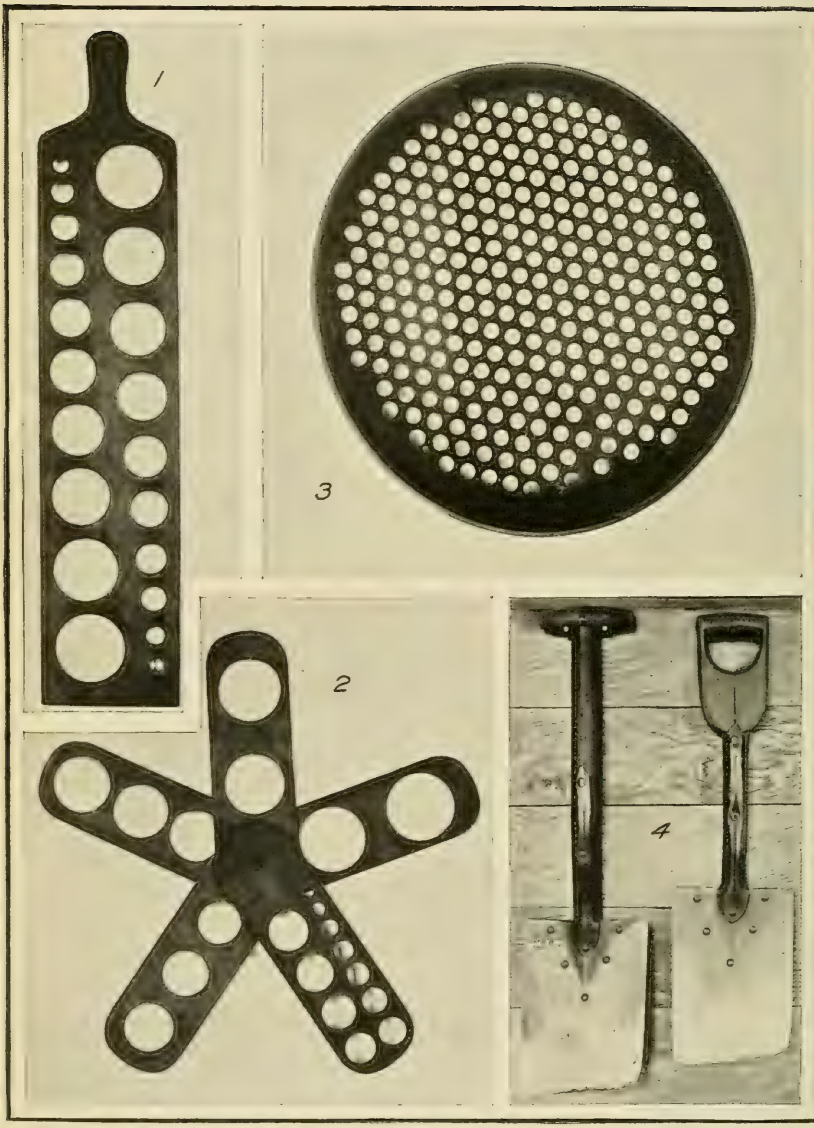


FIG. 2.—SCREENING TULIP BULBS.

In digging large lots the bulbs are screened after digging in a machine such as the one here illustrated, about a bushel at a time. The tray in front of the boy in Figure 1 is shaken by hand to remove the dirt when the lots of bulbs are small.

DIGGING TULIPS.



BULB IMPLEMENTS.

FIG. 1.—A bulb caliper. FIG. 2.—Another form of bulb caliper. FIG. 3.—A bulb sieve with bottom of rawhide. FIG. 4.—Two forms of digging spades. These are the commercial boy's spade with the handle shortened. Note that the blade is wide and flat and the shank quite straight.

economic loss of the bulbs left in the ground there is the added disadvantage of fouling the land. There is no crop which will foul the soil worse than a bulbous one if the digging is carelessly done. The undug bulbs persist. They come up as weeds in the next crop and mix varieties in subsequent years. It is a good practice to go over the fields about blossoming time and dig out all bulbs of the previous crop. This can be attended to at the time the general roguing occurs.

ANNUAL DIGGING IMPERATIVE.

In the commercial production of tulip bulbs the writer has seen no condition under which it is economically advantageous to leave the bulbs undug for two seasons. Such a practice can not be defended except on the basis of expediency; never on the basis of quality or production. The tulip is a gross feeder, and the commercial varieties are so productive in increase of small bulbs that when not lifted annually they are crowded to such an extent that they deteriorate in size and are not merchantable when lifted. (Pl. III, Fig. 2.)

The only condition under which it is considered at all permissible to leave tulips undug is when stocks are being worked up from small sizes and no marketing is contemplated at the next digging. Even in such a case, when the increased weed burden, greater danger of injury from field mice, greater loss from winter heaving, and more laborious cleaning are considered, it is a questionable practice.

It is estimated that the cleaning of biennially dug bulbs takes about three times as much labor as bulbs dug annually. The accumulation of old coats and the thick mat of roots make the cleaning a very laborious process.

DROPPERS.

Tulip bulbs, like many other bulbous stocks, when not planted at the level which they like seek that level by a special process which has been named "dropping." (Pl. XI, Figs. 3 and 4.) This signifies that in the usual artificial handling the bulbs are not planted at the depth which is natural for them. They therefore seek the level which is best suited by dropping or, in some instances, when planted too deep, rising to it. This shift in depth is more likely to occur with the smaller sizes of bulbs and is more prevalent in some species than in the garden varieties.

The change of location is accomplished by a simple contrivance which looks exteriorly like a short stem connecting the location where the bulb was set with its newly acquired position. In reality this connection is simply a fold in the leaf stem which surrounds the new bulb. This fold lengthens, forming a tube, in the end of which the new bulb develops. At times the whole original bulb drops, but most commonly some bulbs are formed in the original situation and

one dropper, the roots always indicating the original position but no roots appearing from the dropper, which is always more heavily coated than the normal bulbs.

THE BULB HOUSE.

The house in which tulips are handled should have provision for the perfect control of both ventilation and light. The heat conditions will be subject to the natural fluctuations of the temperature of the region.

The conventional structure for this purpose has not less than one-third of its wall space made up of partly glazed doors extending from the floor nearly or quite to the ceiling. The interior arrangement is such as to admit of storing the bulbs in layers 4 to 5 inches deep. This is accomplished by the use of stationary shelving or trays, as shown in Plate XII, Figures 1 and 2, and Plate XIII, Figure 2.

The shelves may be built in, about 15 inches apart and 2½ feet wide. They are usually constructed 5 feet wide, with a partition in the center, thus making two shelves, back to back as it were. Between these double rows of shelves are alleyways about 3 feet wide, to permit getting the bulbs in and out.

Trays are stacked in racks made to receive them. They have an advantage over the shelves in that they can be placed closer together, thus economizing storage space; but the trays have the disadvantage of requiring a greater width of alley than the solid shelf. The alleyways for the trays must be wide enough to permit carrying through them the trays loaded with bulbs.

The size of the tray will depend upon a man's notion of convenience. Those employed by the Bureau of Plant Industry at present are 4 feet square and 2 to 2½ inches deep. They should always be constructed of matched lumber, to prevent even the smallest bulbs from falling through and thus mixing stocks. The Plant Industry tray is a 2-man tray; a few trays, however, 2 by 4 feet, can be handled by one man. Some prefer a tray about 3 feet square, which can be handled by one man.

One grower has made his trays 3 by 9 feet. (Pl. XIII, Fig. 2.) These have 2½-inch blocks under their corners, so they can be stacked one on top of the other in piles without racks. These have the advantage of economizing space, but the disadvantage that a tray can not be removed at will for use or for examination without moving all above it. This form of tray is better adapted to large than to small quantities of bulbs of one variety.

THE MANAGEMENT OF THE BULB HOUSE.

Given control of the two factors of ventilation and light, it is a comparatively simple matter to cure tulips properly in practically any region in this country that is adapted to growing tulips. Dry

late-summer and autumn conditions are an important asset in the curing of bulbs both in and out of the ground.

If the bulb house is filled rapidly and to its capacity, there is a proportionately large amount of moisture to be evaporated and gotten rid of at one time. Usually the bulbs come into the house rather slowly, and some should be dry and ready to clean before the last of the crop is dug. It is therefore advantageous to fill first one portion of the compartment devoted to tulips, so that the ventilation can be lessened at one end and put on fully where more needed.

On Puget Sound the ventilating doors of the bulb house usually stand open or partly open during the greater part of the day and are closed at night. This treatment will be all the more emphasized if the location is near the coast. Even 3 or 4 miles inland less ventilation will be required. The advantage of the closed house at night is to assist in keeping up the temperature, which in this location is low.

It should be remembered that tulip bulbs must not dry out rapidly. The curing process is not simply one of evaporating the moisture, but this moisture evaporation is the physically obvious indication of very complicated life processes taking place in the bulbs on the shelves. The drying out, therefore, should not be too sudden. If the bulbs are dug at the proper time to preserve the coats, they will not have turned color completely when brought into the bulb house. In this condition they should not become dried out and ready to handle in much less than two weeks. A little longer time does no injury, and 10 days might be enough.

The directions that can be given for handling bulbs in the bulb house are necessarily very general. The work is one of those jobs that the grower must learn to do by doing. He must learn to know his stocks and to know what they need from day to day.

This does not at all mean that the matter is complicated. It is simple when compared with handling vegetatively vigorous plants in the greenhouse. Indeed, for the past three years at the Bureau of Plant Industry bulb house 300,000 tulips, besides the complement of planting stock, have been cured annually, with little control of ventilation. Operations have been carried on in an open shed with fair success, but the bulbs were cleaned as quickly as possible and then smothered with buckwheat hulls or old sacks in order to protect them from excessive desiccation and light.

"CURING" THE BULBS.

The word "curing," as applied to tulip bulbs as well as to other flowering bulbous stocks, is a misnomer. "Curing" bulbs is an artificial and unnatural process necessitated by commercial handling and not a process required by the stocks themselves. The more

closely, therefore, the conditions of nature can be imitated during the time the bulbs are out of the ground the better they will be preserved. It should be constantly borne in mind that we are dealing with plants whose natural environment is the soil, the multitudinous influences of which are very difficult to imitate. This curing consists simply in drying the bulb clumps as they come from the ground until the old coats appear dry to the touch. The bulbs are dried sufficiently so that mold will not develop. The whole process amounts to striking a balance between an excessive moisture which will allow the development of molds and other decomposition fungi on the one hand and too great a desiccation of the bulbs on the other.

SHELF REQUIREMENT.

The square feet of shelf space needed in the bulb house will vary greatly with conditions. The main factors which influence it are the moisture content of the bulbs when placed in storage, the control of ventilation in the house, and the general atmospheric conditions.

Under conditions which make for rapid desiccation the bulbs can be piled higher and consequently require less room. As a rule, tulip bulbs can go on the shelves 4 to 5 inches deep. (Pl. XII.) As concrete examples of actual performance in this respect Table 2 gives useful information on actual operations wherein the difference will be seen to vary more than 50 per cent.

TABLE 2.—*Space required by tulip bulbs of the Cardinal's Hat variety wnen growing in the field and when "curing" in the bulb house.*

Rows.	Growing space.		Number.		Weight (pounds).			Shelf room used in bulb house (square feet).
	45-foot beds.	Area.	Salable.	Planting stock.	Salable.	Planting stock.	Total.	
3,384	37⅗	About one-fifth acre.	22,000	70,000	1,620	1,120	2,740	260

In 1919 the merchantable turn-off of Cardinal's Hat was 22,000 bulbs, a number large enough to afford trustworthy figures of the space actually employed for handling. In order to have a reliable conception of the bulb-house space, its relation to field space, weight, and number of bulbs is necessary.

The bulbs were dry when dug and of prime quality. Their coats, though, were somewhat cracked, and they were piled higher than usual to get added protection from atmospheric influences. Concerning the 70,000 planting stock it may be said that about 11,000 of these bulbs were below 5 centimeters in circumference and were discarded at planting time.

The drier the situation the less shelf room is required for a given quantity. Indeed, it is found that the new location of these experiments on Puget Sound requires less shelf room for a given area of ground planted than did the old one, although the yield is greater. This is due to drier, better drained soils and to the better atmospheric conditions that exist farther back from the coast.

In handling an acre of tulips in 1920, the bulbs were brought into the house in rotation. The shelf room occupied may be accepted as rather more than is necessary to hold a good crop of these bulbs for the proper curing of stock on such an area at one time under commercial conditions. In practice, when digging is not continuous or rapid it is possible to clean and condense the stocks on the shelves and thus occupy some of the shelf space more than once.

A total of 180 trays 4 feet square held the bulbs from 1 acre for curing in 1920. This in round numbers is 2,880 square feet of shelving, which was ample for a 1-acre crop. It is thought that 2,000 to 2,500 feet of shelving for an acre of tulips under commercial conditions where comparatively large lots of few varieties are handled would be ample.

It will be seen that over twice as much shelf space proportionally was used in the 1920 season in handling an acre as was required the year before for a single variety, Cardinal's Hat, on solid shelves. It will always be true that solid shelving, although not so handy, will be more heavily loaded per square foot than trays. It is also to be noted that in 1919 the crop was much drier when dug, and this particular variety really could have been cleaned without any drying.

CLEANING TULIP BULBS.

The separation of the bulbs from the clumps and the removal of the old coats preparatory to sale and resetting of the stocks are at present done by hand wherever tulips are grown. The work is so variable and of such a nature that it is not clear how a machine can be made to perform the operations successfully, but there are a number of devices which can be used greatly to assist in the process. The operations at Bellingham, Wash., where more than 250,000 tulip bulbs a year have been turned off, have given a fairly good opportunity to study the requirements rather closely.

Emphasis should be put on the fact that if possible tulip bulbs should be cleaned before they are too dry, for the reason that the coats are much more likely to be preserved from cracking in the handling and exposure to light incident to the cleaning if they are not too thoroughly dried out. There is always more or less abrasion, and it is necessary for the cleaners to have good light to work by. The bulbs are consequently exposed for some time to detrimental influences during this operation. Of course, one who grows bulbs on

a small scale and is not selling can very advantageously leave them in the old matrix until the time of planting. In this case the cracking of the coats is not so serious a matter, and the presence of the old matrix may actually be a protection to small lots stored on a make-shift basis. With the commercial grower, however, the case is very different. He must preserve the coats, for more than one reason, and he must separate his merchantable bulbs from his planting stock without unnecessary delay, for the market is always impatient for its bulbs, and the planting season is rapidly approaching.

When the bulbs have reached the proper condition they are removed from the shelves or trays to large cleaning tables, where several men or boys work them over, or the cleaning is done directly from the trays, suitably supported.

It is found to be advantageous to pick out the merchantable stocks by hand and at the same time break all the increase loose from the clump. The large bulbs are placed by hand in receptacles and returned to the shelves, or they may go directly into bags for shipment. The small bulbs, together with the old coats and dirt are left on the table, being pushed to one side by the cleaner until they have accumulated sufficiently, when they are either shoveled or pulled by hand into baskets or tubs, in which they are conveyed to a fanning mill. This machine, with a suitable arrangement of sieves and padding to prevent bruising, removes the dirt and blows out the old coats, leaving the stock clean and ready to be sized preparatory to planting.

A grain-fanning mill is found to be almost indispensable for cleaning the small bulbs. The mill is padded with burlap and usually all sieves but one, which removes dirt, are dispensed with. By exercising care it is found that no particular injury is done by the mill to the smaller sizes of bulbs.

Every operation in the cleaning must be carefully watched, to prevent bruising the bulbs. Inexperienced or careless labor can do irreparable injury in a short time, even by such an operation as tossing bulbs into the containers instead of carefully placing them therein.

The cleaner should have a scoop (Pl. XIII, Fig. 1) close at hand, and the bulbs should be placed in this receptacle and not thrown into it. Such a vessel is much better than a box or pail, for bulbs do not have to be dropped into it, and when it is emptied its discharge of the bulbs into bags or onto the shelves again is much less likely to cause injury.

Piles of bulbs on the shelves or on the tables are generally handled with ordinary iron shovels. At times a homemade, flat-bottomed, wooden hand scoop is used, not essentially different from those sometimes used by grocers; but if care is exercised there need be no more injury from the use of a common iron shovel. For getting the bulbs

off the solid benches the shovel must have its handle shortened, and sometimes the edges are turned up a little and also the shank straightened out, so that it can be operated more advantageously in a smaller space. There is no need to injure bulbs with this tool.

The container scoops (Pl. XIII, Fig. 1) are homemade and constructed in various sizes for different purposes. Where the bulb house is equipped with solid benches close together, this is the only container that can be employed to advantage to load the benches. For this purpose large scoops holding half a bushel are used. Smaller scoops are made for pouring bulbs into pails or bags. The advantage of the scoop over a pail lies in the fact that in transferring bulbs to another receptacle they are not dropped so far from a scoop as from a pail or box.

A convenient table is 4 feet wide for large operations and of any desirable length (Pl. VIII, Fig. 2). It is made tight and smooth with a 1 to 1½ inch edge rail. Sections of this rail at suitable distances are detachable, to facilitate the removal of small bulbs or dirt from the table. The cleaner, when he has accumulated a pile of small bulbs on the table beside him, can remove a foot-long section of the edge rail and scrape them into a scoop, tub, or basket, to be taken away.

It is convenient to have one or two movable partitions (two are shown in Pl. VIII, Fig. 2), which can be moved along, as occasion requires, to accommodate and separate more than one variety on the table at one time. This is simply a board fitting loosely but so close that no bulbs go through between it and the edge rails on either side. Into each end is fitted a small piece of board at right angles, to hold it upright.

Occasionally it will be found that the general plan for cleaning outlined above can be advantageously modified; for varieties differ and stocks of the same variety will vary from one year to another, according to methods of culture, seasonal variation, and other causes. Should tulips for any reason be left undug, there is always a tendency to a multiplicity of small bulbs, which is also likely when a general lack of fertility obtains over a period of years. In such cases it may be advantageous to run the bulbs over an 8-centimeter screen before the large ones are picked over.

Cleaning bulbs is work that requires great dexterity and adaptability. Some laborers perfectly good at other jobs are often unable to do this work advantageously. Those not initiated into the work have a tendency to use one hand only or to take the bulbs up in one hand and break them with the other. Both hands must be used and for the most part independently. It is work that requires good finger strength and consequently can not usually be done satisfactorily by boys under 15 years of age.

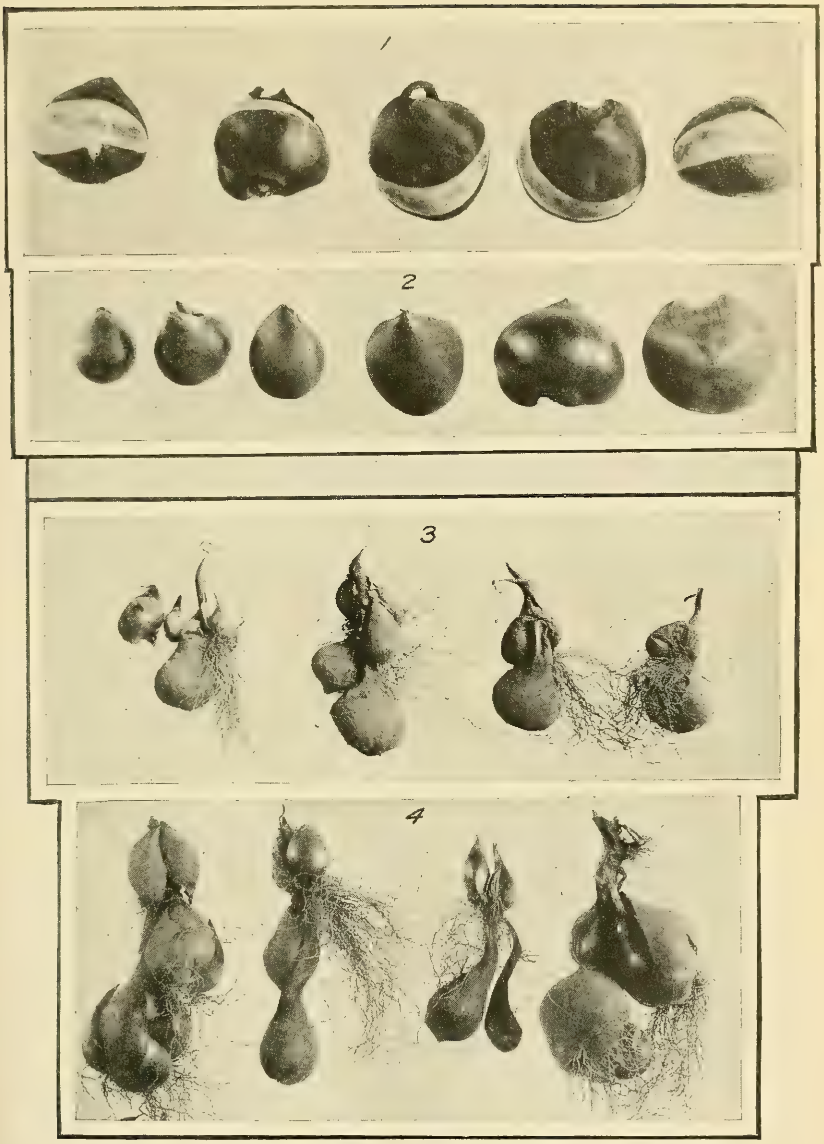
The most common method of work is for the man, with say a square foot of clear space directly in front of him, to pull down from the pile a small bunch of bulbs and spread them out in a single layer. He then picks up the clumps and breaks off the bases. This, also, usually loosens the small bulbs which drop on the table. Five or six bulbs are cleaned in this way without lifting the hands. When the hands are full, the bulbs are put in the scoop and the coarser débris on the floor. No attempt is made to get all the débris off, but only the roughest of it, which interferes too seriously with the operation of the fanning mill. The small bulbs or planting stock are left on the table, to be gathered up from time to time and cleaned in the fanning mill. The cleaning work is shown in Plate VIII, Figure 2.

Short cuts can be made, depending upon the condition of the bulbs. As an illustration, one year these experimental stocks in one variety had a large number of bulblets of 5 centimeters and under, which rounded up into 6 to 8 centimeter bulbs with no increase. When dry the roots and coats were so few as to be of no consequence. These bulbs and bulblets were put through the fanning mill, sized, and planted with no handwork. Handling in this way necessitated keeping these sizes separate on the shelves. Had they been mixed with mature stocks this method of handling could not have been used.

HANDLING THE CLEANED BULBS.

It is of the utmost importance that bulb handling be as simple as possible and that the number of handlings be reduced to a minimum. Consequently, when the marketable stocks have been picked out they should be sorted into first and second sizes at least and then, if possible, go directly into the containers in which they are to be marketed. The writer has recently found that it is feasible to transfer the marketable bulbs from the cleaning tables directly into the conventional paper sack holding 250 to 400 bulbs and set them away to cure in these open containers until two or three weeks later, when they are crated for shipment.

If for any reason it is not practicable to put the bulbs into the permanent packages direct from the cleaning tables, they must, of course, be returned to the shelves, where they can be piled deeper than before. After the cleaning has taken place, two decided changes should be made in their environment. They must not be subjected to strong light; indeed, the light should be much subdued and the ventilation in the bulb house decidedly reduced. Both of these conditions are necessary to preserve the coats and prevent too rapid desiccation. (Pl. I, Fig. 1.) On the other hand, the house must not be allowed to get stuffy, or molds will develop.



CARDINAL'S HAT, GRETCHEN, AND MACROSPHILA TULIP BULBS.

FIG. 1.—Mature bulbs of single early tulip Cardinal's Hat, showing horizontal split across the back when dug. This condition is prone to occur in this and some other varieties on new ground. FIG. 2.—Variation in the size of flowering bulbs in the same variety as shown in Figure 1. There is shown a variation of 6 to 13 centimeters. All of the bulbs flowered the current year. FIG. 3.—Droppers of Darwin tulip Gretchen. The clumps are shown as dug from 5-centimeter bulbs planted 35 to the row and dug at one year. FIG. 4.—Droppers in single late tulip Macrosphila left undug until the second year. It will be seen that there are in some cases two droppers to the same or different levels. Dropping occurred in both seasons.

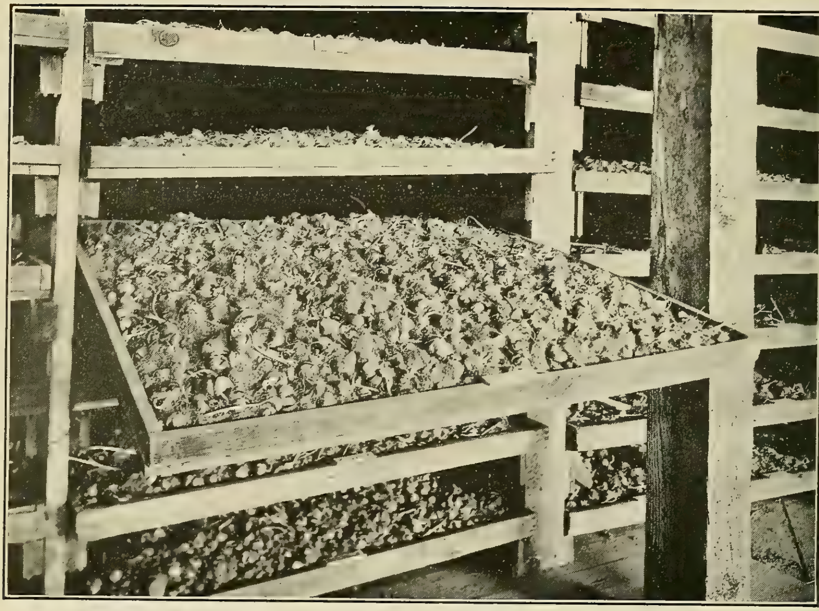


FIG. 1.—A TRAY OF BULBS IN PROCESS OF CURING PULLED OUT OF THE RACK FOR INSPECTION.

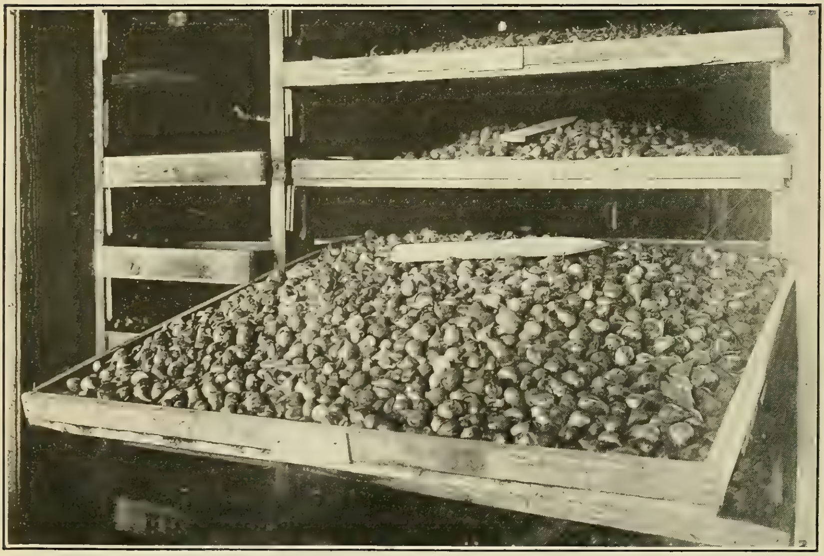


FIG. 2.—A TRAY OF MCKINLEY SINGLE EARLY TULIP BULBS CLEANED AND PARTLY WITHDRAWN FROM THE RACK FOR INSPECTION.

TULIP BULBS BEFORE AND AFTER CLEANING.

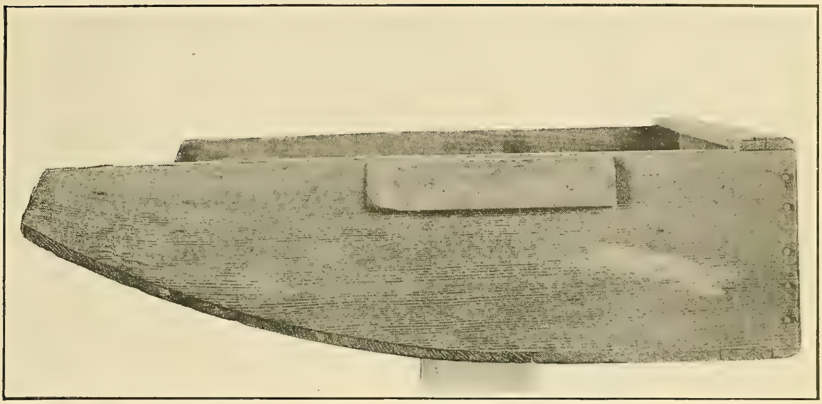


FIG. 1.—A SCOOP FOR HOLDING BULBS.

It is almost indispensable to have several of these around a bulb establishment to facilitate the transfer of bulbs from one place or container to another.

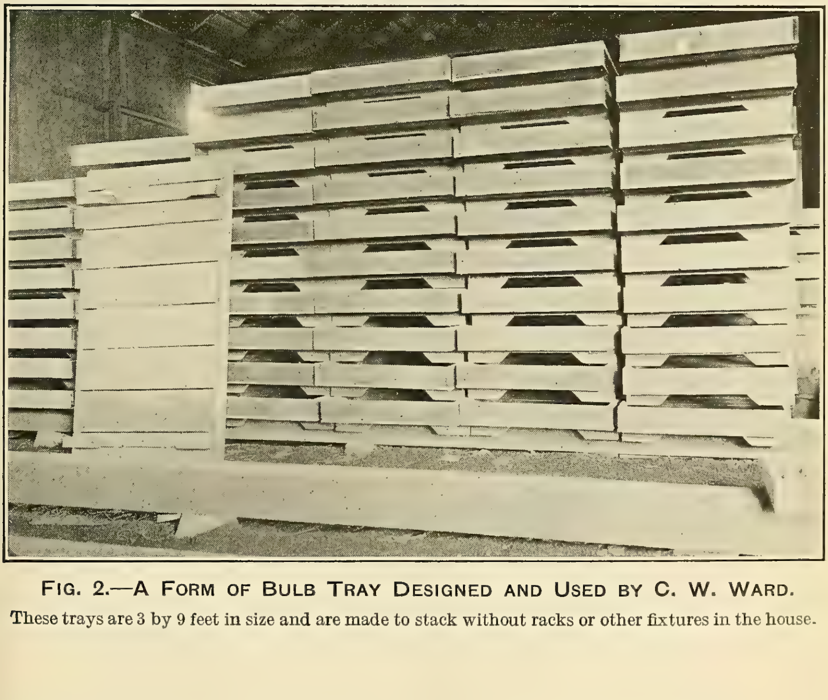


FIG. 2.—A FORM OF BULB TRAY DESIGNED AND USED BY C. W. WARD.

These trays are 3 by 9 feet in size and are made to stack without racks or other fixtures in the house.

FIG. 1.—TULIP BULBS PACKED IN PERFORATED PAPER SACKS HOLDING 250 OR MORE.

Packing material in the form of sawdust, buckwheat hulls, or other grain chaff may or may not be used between the bulbs.

FIG. 2.—SACKS OF BULBS PACKED TIGHTLY IN CRATES.

This shows an entire season's turn-off of the Department's experimental stocks of tulips from 1¼ acres.

PACKING TULIPS FOR SHIPMENT.

When proper control of the bulb house is not possible, it is a good plan to pile the bulbs higher on the shelves and cover them with buckwheat hulls or old burlap sacks.

The above relates to the stock which is to be marketed. The small bulbs which constitute the planting stocks are put through the fanning mill and then returned to the shelves, where they remain until required for planting. They should be handled with just as much care and in practically the same way as the bulbs which are to be marketed. On account of poor aeration it is not safe to pile the smaller sizes of bulbs as high on the shelves as the larger bulbs. They must be kept from molding and from too rapid drying out. In the climate of Bellingham, Wash., when digging is done in July and planting in August, difficulties of this nature are not serious.

PACKING TULIPS FOR SHIPMENT.

Many methods are employed in packing tulips for shipment, the main requisite being a well-aerated pack. For short shipments and small packages aeration need not be considered, but large quantities must be aerated lest they should heat.

The most satisfactory shipments are made in perforated paper sacks holding 250 to 400 bulbs, like those used with imported bulbs. These sacks are packed in slatted crates holding 15 to 20. Shipments may be made both with and without buckwheat or other chaff between the bulbs, and apparently with good success in either case. Often bulbs of the cheaper sorts from Holland placed loose in slatted crates arrive in good condition. The more expensive sorts are always packed with greater care.

Sacks for large shipments are not always readily obtainable in this country, especially in a strength of stock that is required. The Bureau of Plant Industry has used a square-bottomed sack of sterling leather paper having a bursting strength of about 55 pounds, but about 75 pounds is safer, and this is what is used by the foreign grower. Since there is some moisture present, it is important that the sack be well glued. The sacks for large shipments are about 9 by 19 inches, and when filled hold 250 to 400 bulbs. The top is folded, so that a tie once around each way with a stout cord holds. (Pl. XIV, Fig. 1.) At times, cloth sacks holding 1 peck have been used with satisfaction, but there is objection to cloth for the reason that the aeration is not so good as with the perforated paper sack.

The style of crate used by the Bureau of Plant Industry has varied from year to year and, of course, will vary until a bulb business develops in some locality where cooperation and teamwork will standardize operations and materials. The crates now employed are about two-thirds the capacity of the larger Dutch crates.

The crates should be constructed so that a definite number of sacks will fit snugly. (Pl. XIV, Fig. 2.)

IMPORTANCE OF CLOSELY SIZING MERCHANTABLE STOCK.

The value of bulbous stock is dependent in a very large measure upon its uniformity of performance under either forcing or bedding use. One of the most important factors governing this uniformity is the size of bulbs. It is consequently important that the merchantable stocks be closely sized, for the effectiveness of the planting depends upon having the plants alike, the flowers uniform, and the time of flowering the same.

SIZES.

Tulip bulbs are measured in a rather peculiar way, from the American viewpoint. We speak, for instance, of a 12-centimeter bulb, meaning presumably that the bulb measures 12 centimeters in circumference, but it seldom does, owing to its angularity. Although we speak of sizes in circumferences, it is after all diameter that is measured, because the size of a tulip bulb is the periphery of a circle whose diameter is equal to the greatest diameter of the bulb. The bulb caliper (Pl. X, Figs. 1 and 2) is a round hole. Bulbs which pass through an 11-centimeter orifice or screen and are caught by a 10-centimeter screen are called 10 to 11 centimeter bulbs, although the individuals may differ widely in actual quantity of material. This is probably as fair a method as any for measuring such irregular objects.

The sizers are usually so built that sizes varying 1 centimeter in circumference may be sieved out. It is then possible to recognize as many sizes as there are unit centimeters between the smallest and largest size of tulip bulb, or about 12 sizes. In practice, however, the commercial tulip is sorted into two or three sizes, usually referred to as first, second, and third grades or sizes, though the mechanical sizing of tulips has no element of grading in it. Grading is done by culling by hand all imperfect bulbs. Having picked out his commercial sizes, which are mostly above 10 centimeters, the grower resorts to a sizing of the remaining bulbs for his planting stock. It will be seen that the bulk of the Bureau of Plant Industry planting stock runs 8, 7, 5, and under 5 centimeters. The 5-centimeter size really extends from 5 to just below 7 centimeters.

It should be noted that a sizer in the form of a grating (Pl. XV, Fig. 2) will not give the same results as one having round openings for the bulbs to pass through (Pl. X, Fig. 3). In the one case the greatest diameter governs and in the other, the shortest.

WEIGHTS AND MEASURES.

With objects of such variable dimensions as tulip bulbs it is manifestly as impossible to arrive at absolute accuracy in connection with

weights, measures, and numbers as it is with potatoes or any other similar crop.

The data in Table 3, worked out in August, 1920, ten days to two weeks after the bulbs were cleaned, may be accepted as representative. Counts and measurements were made of the bulbs as they had dried out for that length of time on the shelves in a bulb house which was poorly controlled.

TABLE 3.—*Relation of weights and measures of tulip bulbs.*

[All bulbs flowered this year except those of Farncombe Sanders.]

Name of the variety.	Size of bulbs (centimeters).		Bulbs to a bushel.		Number of bulbs in a pound.	Remarks.
	Planted.	Dug.	Number.	Weight (pounds).		
Farncombe Sanders	8+	11 to 15	770	$54\frac{1}{2}$	$14\frac{1}{5}$	About half of the bulbs were long necked.
Cardinal's Hat	8+	11 to 13	1,050	$56\frac{1}{2}$	18+	Bulbs rather undersized.
Clara Butt	8+	10 to 13	980	56	$17\frac{1}{2}$	
Crimson King	8+	9 to 12	1,295	56	$23\frac{1}{2}$	
Macrosphila	8+	10 to 12	1,148	$56\frac{7}{8}$	20+	Stock planted last autumn.
Do	8+	[a] 9 to 13	1,855	56	$33\frac{1}{8}$	Stock undug last year.
Fairy Queen	8+	11 to 13	944	56	$16\frac{6}{7}$	

[a] Mostly 9 to 10 centimeters.

From Table 3 it will be seen that the weight of a bushel of bulbs is quite constant, and 56 pounds has been adopted as the weight of a bushel measure slightly rounded. So far as known, no standard weight of a bushel of tulip bulbs has been established. The number of mature bulbs in a bushel will manifestly vary greatly with the variety, as will the variety under different methods of handling and the crop of one season with that of another.

PREPARATION OF STOCKS FOR PLANTING.

Let us assume that the stocks are all cleaned and returned to the shelves. Some work must still be done on them before they are ready to plant. The method used in sizing the bulbs will depend upon the kind of machinery employed. Except where the operations are large and the equipment ample the work is likely to be done on a makeshift basis. But if any quantity of bulbs is to be sized, the grower can not well get along without about four nesting sieves. (Pl. X, Fig. 3.) This will allow of a separation into five sizes. For moderate quantities of bulbs the sieves can be operated by hand, but it is decidedly advantageous to construct a shaker, as shown in Plate XV, Figure 1. This holds the nest of sieves and may make a separation at one operation of about one-third of a bushel into five sizes.

When these separations have been made, each size is placed in a different container, labeled, and sent to the field in lots, each lot

representing a variety sized as they are to be planted. The containers for this work may be any suitable receptacles. It is the practice of the Bureau of Plant Industry to use lug boxes, tubs, and sacks, according to the quantity of each size planted. In commercial work, where the number of varieties is reduced to a minimum, this matter is very much simplified.

IMPLEMENTS OF TULIP-BULB PRODUCTION.

Ordinary farm tools suffice to put the land in condition for tulip culture. A plow, harrow, disk, rolling-disk packer pulverizer, and at times graders and ditchers are the implements employed.

The special tools are few in number and simple in construction. Usually they can not be bought ready made in this country, but must be homemade or made to order. Such tools, however, present no difficulties which any carpenter or blacksmith can not overcome.

Marker.—The marker (Pl. VI) is essentially a revolving drum, so constructed that it marks the center and margins of a 3-foot bed, together with rows 6 inches apart across the bed. It is a simple implement, having solid circular ends of wood 18 inches in diameter, these being held in place by slats set in the periphery 6 inches apart, for marking the rows. Another board wheel into which the cross slats are mortised is placed in the center of this roller marker for rigidity. Then by binding over the end and center wheels with a hoop, which may be one-fourth to one-half inch thick, the center and margins of the bed are marked with longitudinal lines. Through the center runs an axle, to which the operating handles are attached.

Screens.—Screens for removing the loose dirt at the time of digging are indispensable in any considerable operation in bulb culture. They are simply rectangular shallow boxes 14 by 22 inches in size and 4 inches deep with galvanized-wire bottoms. A mesh of one-fourth inch is the most serviceable for tulips. (See Pl. IX, Fig. 1.) The ends of these trays are reinforced with an extra thickness of board. This gives greater rigidity and allows for the construction of a handhold without impairing the safety of the contents while the sieve is operated.

Besides these hand screens, which are used for small and moderate quantities of tulips, there are larger machines, usually spoken of as shakers. They are rectangular boxes mounted on a frame in such a way that the contents may be agitated vigorously to remove dirt. They handle about a bushel of bulbs. This machine, well illustrated in Plate IX, Figure 2, consists of a rectangular tray, like the small hand sieve, but the box is 2 feet 4 inches wide, 6 feet long, and 8 inches deep. It also has a $\frac{1}{4}$-inch wire-mesh bottom. About 15 inches from one end there is inserted a removable slide partition, and the wire bottom terminates at the slide. Over the opening back of the slide

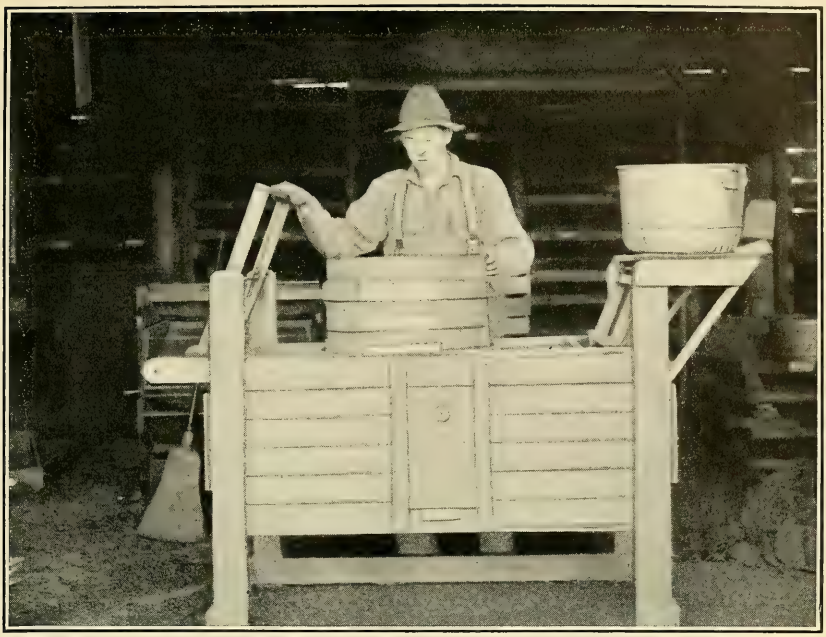


FIG. 1.—CONVENTIONAL RAWHIDE NESTING SIEVES SHOWN IN USE.

Three sieves are shown nested on a carrier which may be vigorously shaken by hand. The use of three sieves gives four sizes, one below 5 centimeters in this case falling into the pit below and being removed through the sliding door.

FIG. 2.—SIZING BULBS BY ANOTHER METHOD ON AN ENTIRELY DIFFERENT PRINCIPLE.

By the apparatus shown in Figure 1 the longest diameter of the bulb governs, while in this the shortest diameter governs.

SIZING TULIPS.

SINGLE EARLY VARIETIES AND A DARWIN TULIP.

FIG. 1.—Yellow Prince. FIG. 2.—Sieraad van Flora, one of the robust Darwins. FIG. 3.—Thomas Moore.

is fitted a bottomless cloth tube (usually an old sack). By proper manipulation of this screen-bottomed box on its support, the contents can be "jerked" out of this opening, upon the removal of the slide partition, without touching the bulbs by hand. In this way the bulbs are mechanically and expeditiously transferred to the lug boxes with a minimum of labor.

A modification of this shaker is often employed. This consists essentially in dispensing with the frame and mounting the screen-bottomed shallow box on a piece of pipe between two supports, so that when empty it just tilts toward the operator, and the near end is supported by a short stick which holds it at a small angle with the horizontal. A bushel of bulbs is oscillated back and forth by rotating the box through a small arc on the pipe support. This is the form of machine generally used by Hollanders in this country.

Digging spades.—While there are no tools on the market adapted to bulb digging, it is possible to remodel tools to serve the purpose. (Pl. X, Fig. 4.) A boy's spade with the handle cut down to 16 inches makes a very serviceable tool. This is done by setting the D handle lower down, or by simply cutting off the handle at the proper length and attaching a crosspiece in the form of a T for a handhold. This makes a spade about 22 to 24 inches over all.

The main requirements for this tool are that the blade be flat and the handle as nearly straight as possible. This spade is never used to lift the soil, but simply to pull it toward the workman. To do this it is necessary to have the blade flat on account of the small space between the rows. Otherwise, there is greater danger of cutting the bulbs.

Planting boxes.—In the field at planting time it is necessary to have small, light, shallow boxes holding 4 to 6 quarts of bulbs. (Pl. VI, Fig. 2.) These are especially useful in planting the smaller sizes, as it is not profitable to strew them along the beds from the lug boxes as is done with the larger bulbs. With us, these are made of three-eighths and one-half inch light wood and are 12 by 12 inches and 3 inches deep, inside measurements. These should be well and smoothly made and light.

Scoops.—Scoops are essentially pouring vessels, but are also very useful on the tables at cleaning time to receive the bulbs as they are cleaned. They are made as shown in Plate XIII, Figure 1. They are useful in various sizes, from a peck to a half bushel.

Sizers.—The most common sizer (Pl. X, Fig. 3; Pl. XV, Fig. 1) used for moderate quantities of tulips is a circular, sievelike instrument, with a bottom of rawhide in which are cut holes of definite circumference. In some cases wire screens are used for this purpose, but the bulbs are much less likely to be bruised by rawhide.

Another tulip sizer is shown in Plate XV, Figure 2. This is essentially a chute or inclined plane made up of sections of parallel gratings,

over which the bulbs roll until they come to openings large enough to pass through.

In the Netherlands, various other forms of sizers are employed. The "Vlinder" is probably the most widely used machine. It is essentially an oscillating plane made up of sections of rawhide perforated in accordance with the conventional methods of sizing bulbs.

Another machine is a hexagonal revolving drum made up of sections, each of which separates one size of bulb. It is similar in principle to the common gravel screen used in this country.

Calipers.—These instruments are used to measure individual bulbs. One form consists of a thin piece of veneered wood in which are bored holes varying usually from 3 to 23 centimeters in circumference. (Pl. X, Fig. 1.) A more convenient form is put up in five veneered strips about 3½ by 12 inches, superimposed upon each other and fastened together so as to open like a fan. (Pl. X, Fig. 2.)

Blowers.—The blower used in this work is a grain fanning mill, with the wind, sieves, and padding so adjusted as to accommodate the handling of planting stock of bulbs. This winnows out the dry scales and light material from a mass of small bulbs. (See p. 22.)

Lug boxes.—The lug boxes used need not be essentially different from the fruit lug box, and they are used in the same way in hauling bulbs from the field at harvest time and back to the field again at planting time. These should, of course, be as light as consistent with the necessary strength.

Spud.—A good spud is an essential tool for roguing, i. e., taking out stray bulbs from the beds at blossoming time, when they can be most easily detected. It can be made with a strong fork handle 30 inches long, attached to a steel blade 2 inches wide and 8 inches long with a short curved shank inserted into the handle through an ordinary ferrule. This has been found the most serviceable tool for removing a bulb from a thick planting with as little disturbance as possible of neighboring bulbs.

Trowel.—The common garden trowel used in this country is poorly adapted for use among bulbs. A tool of this kind with a flat blade is much more serviceable. In very light soil such a tool can be used for digging.

THE DUTY OF LABOR.

In any consideration of the duty of labor the climatic factor plays a very important part. Tulip-bulb production can be conducted best in a region of relatively low, uniform average temperatures, and this is where labor is most efficient. If the digging and planting of the bulbs must be done in very hot weather, labor efficiency is very much reduced. On Puget Sound the weather conditions are ideal

In summer, when the heavy work occurs, the temperatures are seldom up to 80° F., a condition most favorable to the efficiency of labor.

The following account of the cost of growing an acre of tulips must be considered excessive from a commercial point of view. It is to be looked upon as the cost of experimental culture, but it is the only available record in this country. It will serve as a basis for the estimate of cost until such time as it may be possible to secure cost accounting from commercial growers.

The cost of the different operations is given in some detail, the better to enable the grower to form his own judgment.

Digging.—The best information as to efficiency in bulb digging can be gleaned from an account of actual performance on the Whatcom silt loam, which is a heavy soil near Bellingham, Wash. In the summer of 1920 the short acre of tulips was dug between June 22 and July 14. During the greater part of the time that digging was in progress the crew consisted of one experienced man, four boys with one year's experience, and three boys without previous experience. Considering all the labor on the same basis, it took a total of 61 days to dig the acre. Putting the matter another way, the workers dug in a day an average of three beds 42 feet long. This is 126 feet of a 3-foot bed in 8 hours. Under the conditions of heavy soil and the large element of inexperience in the labor, this may be considered a very fair average for an 8-hour day for a month's digging. It should be noted, however, that at the end of the month some of the boys were able to accomplish about twice their average at the beginning. The average at the beginning was only two beds a day, while toward the last each boy was able to dig 3½ to 4 beds in a day.

Cleaning tulips.—It has never been possible at Bellingham, Wash., to get an estimate of cleaning continuously an acre of tulip bulbs. At no time has it been possible to put a definite number of men on the job and keep them on until they were through. At various times, however, the boys have been timed on representative squares of shelving.

When the bulbs are normal and the trays are well rounded an active boy will clean four trays, but when not so full, as described under "Shelf room required," he will clean five trays, or 80 square feet of tray space, in a day of eight hours. This means that the large bulbs are picked out and the planting stock blown by a fanning mill as described elsewhere. Extending this data to the acre unit, it means that a man or active boy will clean the product of an acre of tulips in 30 to 35 days.

Marketing.—There is no use in attempting to get at the labor cost of marketing an acre of tulips, for the reason that this depends upon varying conditions that would be hard to duplicate. The Depart-

ment of Agriculture has usually shipped a minimum carload in bulk. With containers ready and tulips cleaned on the shelves, four men one year packed 300,000 tulips in a little over a day. But this was what might be termed "bulk shipment." The filling of small orders would be slower, and more time would be consumed in proportion to the number of the orders. It is believed that the cost of marketing tulips will not differ very much from that of marketing gladiolus.

Planting tulips.—Commonly the planting crew consists of two men and four boys. A crew as large as this is used because inexperienced boys are not able to keep bulbs set ahead of the two good men mucking and raking. Usually with a little experience and selection boys may be found, two of whom can do the work. It is considered that a good planting crew consists of two men and two adaptable, experienced boys. Such a crew as this has put in 25 beds a day. One crew of this size put in an acre of tulips on two occasions in a little less than eight days. The same performance was duplicated last year. Mr. Houser, who managed the crew both years, is of the opinion that such a crew after two weeks' experience should be able to put in an acre in seven days.

Cultivation.—Under cultivation is included all work done on the ground in the way of raking, fall and spring cultivating, and hand weeding. It is interesting to note that one man spent 1½ days in hand weeding 1 acre for the 1920 crop. The total time on this work was 18 man-boy days.

Marking and opening the beds.—Boys did the work of marking and opening the beds on the acre in 10½ days.

Sizing and storing.—The time required for sizing and storing tulip bulbs in the experiments at Bellingham, Wash., is much in excess of that necessary for commercial operations, on account of the multiplicity of varieties. One man occupied on this and other miscellaneous duties worked 16 days.

Roguing.—It took one man 4½ days to rogue the acre of tulips in 1920.

Cutting flowers.—To remove the flowers from the beds and compost them took the labor of one man for 6 days.

TABLE 4.—*Labor of growing an experimental acre of tulip bulbs.*

Operation.	Labor summary: Man-boy labor (days).	Operation.	Labor summary: Man-boy labor (days).
Digging	61	Sizing and storing	16
Cleaning	35	Roguing	4½
Planting	48	Cutting flowers	6
Cultivation and weeding	18		
Marking and opening beds	10½	Total	199

Labor summary.—The labor of growing an acre of tulip bulbs is summarized in Table 4. To arrive at the total cost the interest on the investment must be added and also the cost of preparing the ground, which will not differ materially from the preparation for potatoes or any other similar crop.

SOILS.

A soil which will not bake is suitable for the production of tulip bulbs. If it is light and friable, it will be much more easily handled. If it is lean and sandy, the cost of fertilizer will be heavier, but this will probably be compensated by a much lower charge than is required for handling a heavy loam.

FERTILITY OF PARAMOUNT IMPORTANCE.

That tulip bulbs of good quality can not be produced on infertile soil should be recognized as axiomatic. The numerous failures experienced by the householder who has endeavored to continue his stocks of bulbs year after year are due to a lack of proper soil fertility more than to any other cause. Tulip stocks of practically all varieties "go all to pieces," so to speak, when grown year after year on poor soil.

EXCESSIVE FERTILITY.

While tulips, like most bulbous stocks, require heavy fertility, it is possible to apply too much raw manure for them to give best results. An application of manure too near the time of planting, even though it be not excessive in quantity, is also likely to cause injury. A heavy application of manure with the removal of some other crop previous to planting the bulbs furnishes the ideal condition for tulips.

Excessive stimulation often manifests itself in the tulip by a large approximately horizontal gash in the coat across the back of the bulb, as well as by excessive size. (Pl. XI, Fig. 1.) The bulb seems to expand at too great a rate for the coat, which is ruptured and slightly wrinkled, as well as somewhat thickened over the remainder of the bulb. This is very different from the irregular splitting of the coats due to too great exposure. Here the split has already occurred before the time of digging, and the white, living scales beneath are already somewhat discolored by contact with the soil.

Such conditions are likely to occur to some extent when tulips are grown on new, fertile soil, even though it be not heavily fertilized, but in the absence of added manures it is not likely to be serious.

Some varieties are much more susceptible to injury from this cause than others. Cardinal's Hat is very susceptible. In 1919 the stocks of this tulip at Bellingham, Wash., had not over 5 per cent of

perfect bulb coats in the merchantable sizes when dug. The planting was on newly cleared cut-over Whatcom silt loam which had received an application of 12 loads to the acre of half-rotted stable manure in May previous to planting in August and one crop of rye turned under. The size of the bulbs under these conditions was very much larger than normal, measuring fully 13 centimeters as against 9 or 10 centimeters under low fertility and 10 to 11 centimeters for the optimum.

THE SOURCE OF THE FERTILITY.

One thing above all others should be impressed upon the American tulip grower, i. e., that cow dung is not the only source of fertility that can safely be used; indeed, in fertile soil with good cover crops no animal manure may be necessary.

Stable manure from which the "fire" has gone seems to be as good as any fertilizer. Sheep manure gives good results, and bone meal can not be surpassed, but it is too expensive for liberal use.

The nature of the soil will have a great deal to do with the kind of fertility demanded. On our heavy silt loams humus is needed to give porosity and tilth and opportunity for percolation of water, which these soils do not naturally have.

To put the matter tersely, the crop is no more exacting in the nature and origin of its required fertility than any other farm crop. It demands plenty of it, but is not particular as to its source, which means, as in other farming operations, that the grower will resort to whatever source of fertility is available to him. Commercial fertilizers can best be supplemented by cover crops and other means of adding humus.

DISPOSAL OF CROP RESIDUES.

As with many other horticultural crops, care should be exercised in the handling of the refuse from tulip-bulb production. This should not be burned or otherwise wasted, but should be handled so as to avoid its use on land which is to grow tulips or other bulbs, as an added precaution against the spread and accumulation of the spores of fungi which cause diseases. This is a very important matter and should not be overlooked.

This débris, made up largely of stems and leaves hoed off the beds at digging time, flowers cut off before the petals drop, old coats, and imperfect, rotted, and undersized bulblets, cleaned out of the stock during the time it is in the bulb house, should be composted and thoroughly rotted before being used on any ground; otherwise the bulbs will come up as weeds in other crops and be a source of annoyance and loss indefinitely. There are few weeds more persistent in cultivated fields than tulips which have been left undug or plowed in with unrotted compost.

DRAINAGE.

Whether the producer of tulip bulbs will be obliged to give serious thought to drainage will depend entirely upon his location. Even with the heavy precipitation of the Puget Sound region, level culture can be practiced on all the Lynden sandy loams except where they lie low and their water table is naturally high. On the Whatcom silt loams, however, the case is very different. Here careful ditching is required. Although the present location of the Bureau of Plant Industry plats is rolling and in the main contains sufficient fall, it is found necessary to maintain ditches down to the clay subsoil along the sides of each plat. Ditches have been dug on both sides of the roadways, and roadways around each two plats have a ditch between. This system seems to be necessary even though the plats run across a well-drained slope, i. e., when the drainage is good in the direction of the length of the bulb beds. Were it not for these ditches to intercept and carry off the drainage waters, the lower plats, even on hillsides no longer than the width of two plats (100 feet), would be too wet in the winter and during the growing season until May.

In shaping up the ground preparatory to planting, care is also exercised to contour the plats so as to get a gradual fall from the centers to the ditch on either side. The greater part of this is accomplished by plowing toward the center of the bed.

Even with beds only 40 to 50 feet long and the plats bedded up in the center, it is found that the conditions for growth on the ends of the beds are far from perfect for two reasons: (1) There is an accumulation of moisture to a detrimental degree in the first 4 to 6 feet along the ends of the beds, although the drainage slope is not over 25 feet in length; (2) owing to the building up of the center of the bed on soils which are so shallow, the ends of the beds are too close to the subsoil and have too much refractory clay in their make-up to let go of the surplus moisture as rapidly as desirable. The result is that the soil at the ends of the beds is likely to be hard and difficult to dig and the crop commonly much poorer than in the center. In extreme cases the bulbs so located rot, and nothing but old coats is to be found at digging time.

It will be readily appreciated that the contouring and ditch maintenance are expenses which are, of course, not necessary on well-drained lands.

WHERE TULIPS MAY BE GROWN.

That tulips are an exacting crop, as commonly supposed, must be most emphatically denied. There are certain requirements for their best culture, it is true, but these requirements can be satisfied over a comparatively large extent of territory.

Wherever soils are suitable, the Puget Sound territory is admirably adapted, as, indeed, is the whole Pacific coast from northwestern

California northward. Successes have been had in Michigan. Good bulbs have been grown on a small scale in Virginia, New York, Vermont, and Ohio. One success is recorded in southwestern Missouri, although confessedly under difficulty and only with Darwins and late tulips. Many more illustrations might be cited, but the above are sufficient to prove the contention that the crop is quite adaptable.

The main requisites are, first of all, a soil that does not bake, plenty of moisture, good drainage, and a not too rapid transition from winter to summer.

ENEMIES OF TULIPS.

If the tulip grower observes the rules of ordinary sanitation and good culture and rotates his crops so as not to get back on the same ground with tulips oftener than once in three years he seldom need worry about diseases. The tulip is remarkably free from pests. The popular notion that mysterious scourges come along and wipe out the crop is fallacious. Even a bulb so badly injured that it can not make root is often not lost. There is frequently a good, uninjured bud which will commonly round off into a perfectly healthy but small bulb which can be grown so as to give a normal progeny again. Often bulbs have been seen so injured by molds or poor drainage in winter and early spring that they died down four weeks before their time but left a perfectly healthy bulblet, although only a tenth of the size of the original.

The most serious enemy of the tulip bulb is the bulb house. Here all sorts of abuses are practiced which may lead to disaster, but the rots and the molds of the bulb house are no more diseases of the tulip than the same rots and molds are diseases of bread and pastry in the kitchen pantry. Of course, if the moisture conditions are not under proper control, bulbs in piles will rot, but so will wheat and corn, and it may be said that a properly cured tulip bulb with its coat on is about as effectively protected from fungi, either saprophytic or parasitic, as a grain berry. If the coats are abraded and the bulbs bruised, of course, the ordinary black and blue molds will find ingress and do great injury, but this is also true of potatoes.

Second to the "bulb-house pest" should be mentioned the fire disease, caused by the mold Botrytis. (Pl. VII, Fig. 2.) This is really the only disease of consequence which has affected tulips in this country. This saprophytic mold under certain favorable conditions is capable of becoming a real parasite, attacking and destroying living tissues.

When this disease appears in the bulb fields, little can be done to check its progress. It is said that the Hollander drives stakes around a focus of infestation and stretches muslin to prevent the spores being spread by the wind to healthy foliage, but it has never been thought that such a remedy was practicable in any attack observed by the

writer. In certain classes of infestation, wherein scattering leaves through the planting are "fired," it is advisable to go through and clip with shears the diseased portions and carry them out of the field.

Weeds allowed to grow to such an extent that good aeration is wanting contribute to the development of the fungus. Some fire has occurred in these experiments even on virgin soil when tulips have been left in for two years, although properly handled stocks close by were so clean that no fire could be detected.

To sum up, clean culture, safe rotation, sanitation in matters relating to the residues of the crop, annual lifting, care that the planting stock be not bruised, or allowed to become moldy or to be skinned in the bulb house are the preventive measures which will render diseases of the tulip negligible.

We may possibly consider as an exception to the above statements the mosaic disease of tulips known as "breaking." Investigations of this disease are now in progress, and it will be well to refrain from positive statements on the subject until authoritative information is obtained. A provisional discussion of this subject, however, will be of value in this place, giving the results of the observations and opinions of the writer and his horticultural associates.

The "broken" tulips are sold as a distinct race by the florist. They are listed as Rembrandts when derived from the Darwin section (Pl. XVI, Fig. 2, and Pl. XVII) and as "broken" tulips in other sections of the tulip lists. They are distinguished by the peculiar variegated or mosaic patterns of the floral coloration. These same patterns extend into the leaves and other portions of the plants, where the contrast of coloration, however, is less spectacular than in the flower, because the breaking in the leaves consists in simply an unequal distribution of the green coloring matter which results in a delicate and often only indistinct pattern of varying densities of green. In the flowers, however, especially when the ground color or the color of the tissues between the epidermal layer is yellow and that of the epidermis some brilliant shade, the pattern becomes striking and often very beautiful. There is an exact counterpart of this in the flower of the ornamental tobacco affected with the mosaic disease, which has been extensively studied by Allard and others.

The effect of the disease on tulips is precisely similar to the effect of the mosaic on tobacco. There is a decided dwarfing of the plant, a reduction of its powers of reproduction, and a general weakening of its constitution. The "broken" tulips, therefore, are less satisfactory to grow, especially if one is producing bulbs for sale, than the self-colored forms. In short, the mosaic or broken plant is weak and requires greater care and effort in the production of marketable stock from it. The breaking in tulips is again analogous to mosaic in that seedling stocks of broken strains are free from the disease.

At Bellingham, Wash., broken tulips have not been grown, and the stocks, many of which have been grown there for 15 years, numbering between 250 and 300 varieties, have not broken.

Any self-colored tulip (and all tulips grown from seed are self-colored) may become broken. The statement is sometimes made that the single early tulips do not break, but this is true in the florist's sense only. These break just as truly as the others, but they give in the breaking no spectacular patterns such as are found in other groups; on the contrary, the brilliancy of their floral coloration as well as their general vigor is reduced. Consequently, the broken plants in this group are rogued out of the stock.

The cause of breaking in tulips has not been demonstrated, neither has it been investigated until recently with the idea of its disease origin in mind. Nor for that matter has the real cause of mosaic diseases in other plants been demonstrated, although extensively studied. The essentials of communicability, effect on the host, carriers, and preventive measures are well worked out, however. As in tobacco, it is probable that here again the aphis is the main carrier of the disease. Fortunately the aphids have never been numerous in the bulb fields at Bellingham, Wash.

With this information before him the bulb grower should consider carefully before he attempts to introduce broken stocks into his plantings. It is known that the disease is communicable to self-colored stocks. There is, consequently, grave danger of his self-colored stocks becoming ruined if broken stocks are introduced, for when once broken they can be sold only as mixed tulips. The production of bulbs of these mosaic varieties should not be attempted except at safe distances from the regular self-colored stocks.

A peculiar trouble sometimes occurs in tulip bulbs when grown under adverse conditions which has caused growers concern because interpreted to be a disease. It manifests itself in the form of an imperfectly filled bulb coat. The base of the bulb may be quite normal and well filled but reduced in size, but the tip may be empty and wrinkled, as is well brought out in Plate VII, Figure 1. This condition has been observed in many varieties on the Pacific coast when planted shallow and late on very light soil that dried out too quickly in the spring.

WHY SOME VARIETIES ARE CHEAPER THAN OTHERS.

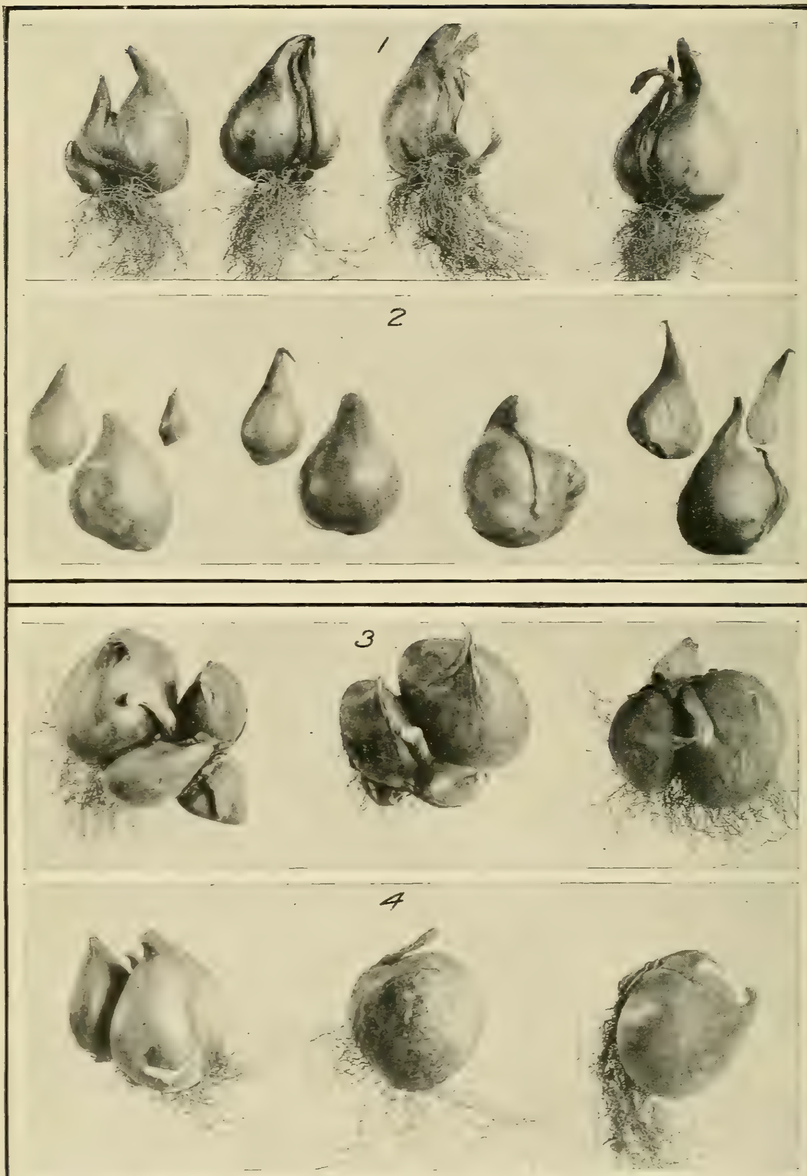
It is not necessary to discuss values in novelties or new varieties of which only limited stocks are available. Here the law of supply and demand and a desire for the new govern, as in any other commodity.

Leaving aside entirely the facts of actual merit, popularity, and consequent general demand, there are some varieties which can

FIG. 1.—A DARWIN TULIP PLANTING IN EARLY SEASON BEFORE THE FLOWER STEMS ARE SHOWING.

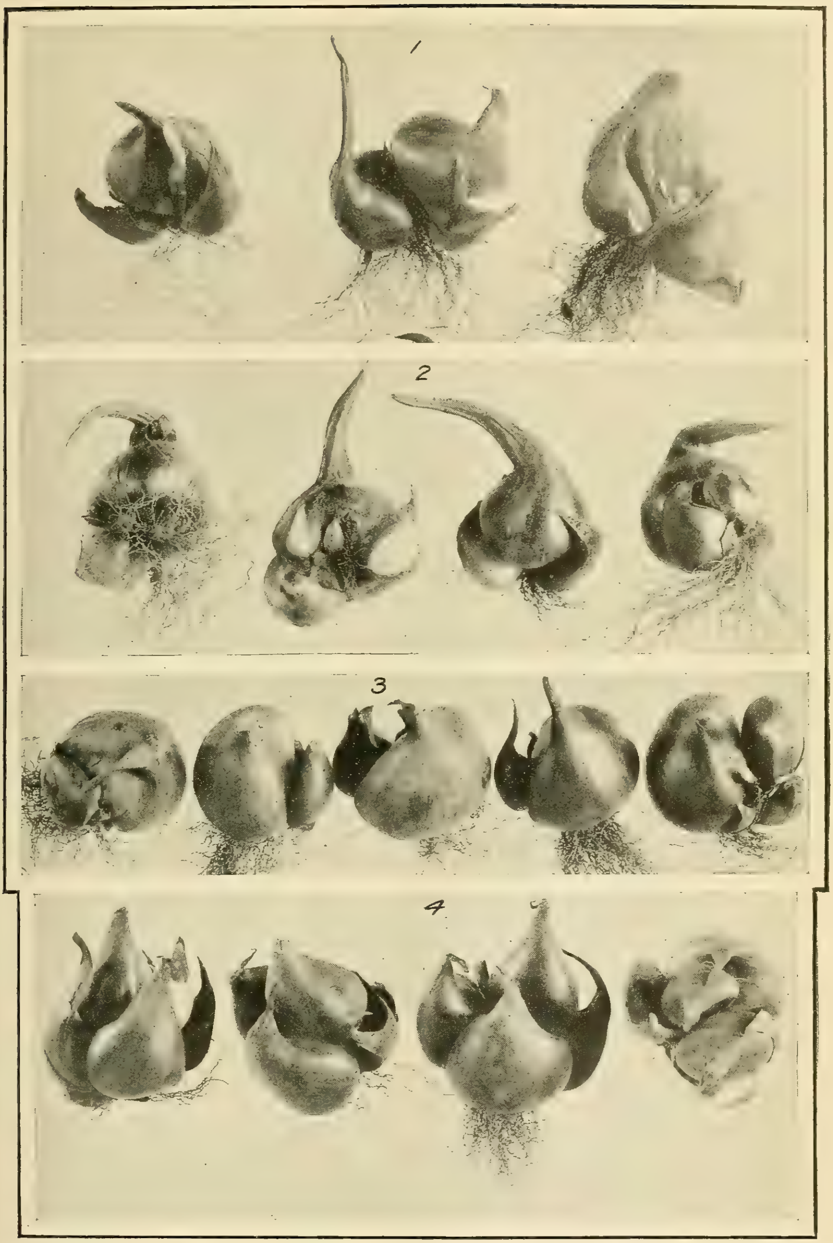
FIG. 2.—A PORTION OF THE FIELD SHOWN IN FIGURE 1 WHEN THE BULBS ARE IN FLOWER.

DARWIN TULIPS.



PROSERPINE AND KEIZERKROON TULIP BULBS.

FIG. 1.—Four clumps of Proserpine dug from 8 to 9 centimeter bulbs set 14 to the row. All flowered, but all did not propagate. FIG. 2.—The same bulbs shown in Figure 1, cleaned and separated. The variety reproduces poorly, which is the main reason for its comparatively high price. FIG. 3.—Reproduction in Keizerkroon from 10 to 12 centimeter bulbs planted 14 to the row. The bulbs were imported in the autumn of 1918 and used for bedding. They were dug as soon as the flowers had faded, heeled in to ripen, and were dug again early in June, 1919. The results are for the 1920 crop when the bulbs had become normal, but probably had not reproduced as well as they would have done had they ripened properly the previous year. FIG. 4.—Reproduction in Keizerkroon 8-centimeter normal bulbs which have been in the country 10 years. This popular variety is not prolific of increase.



REPRODUCTION IN CALLIOPE, FAIRY QUEEN, AND FULGENS TULIP BULBS.

FIG. 1.—Reproduction in Darwin tulip Calliope. There were planted 8 to 9 centimeter bulbs 14 to the row, which have grown to 11 to 12 centimeters, flowered, and produced an increase of two 10, three 7, and two 5 centimeter bulbs. FIG. 2.—Reproduction of the same variety as Figure 1, but 7-centimeter bulbs were planted 21 to the row. They have grown to 11 to 13 centimeters, with an increase of one or two 7-centimeter flat bulbs each. FIG. 3.—Reproduction in Cottage tulip Fairy Queen. There were planted 8 to 9 centimeter bulbs 14 to the row. This is a good tulip, but not as good a reproducer as some. FIG. 4.—Reproduction in Cottage tulip Fulgens, showing a wonderful increase in 8 to 9 centimeter bulbs set 14 to the row. The four bulbs have yielded three 11, three 10, and two 9 centimeter flowering bulbs, besides one 9, two 8, five 7, three 5, and two 4 centimeter bulbs for growing on.

FIG. 1.—A VERY SATISFACTORY REPRODUCTION.

The bulbs planted were 10 to 12 centimeters in circumference and set 11 to the row.

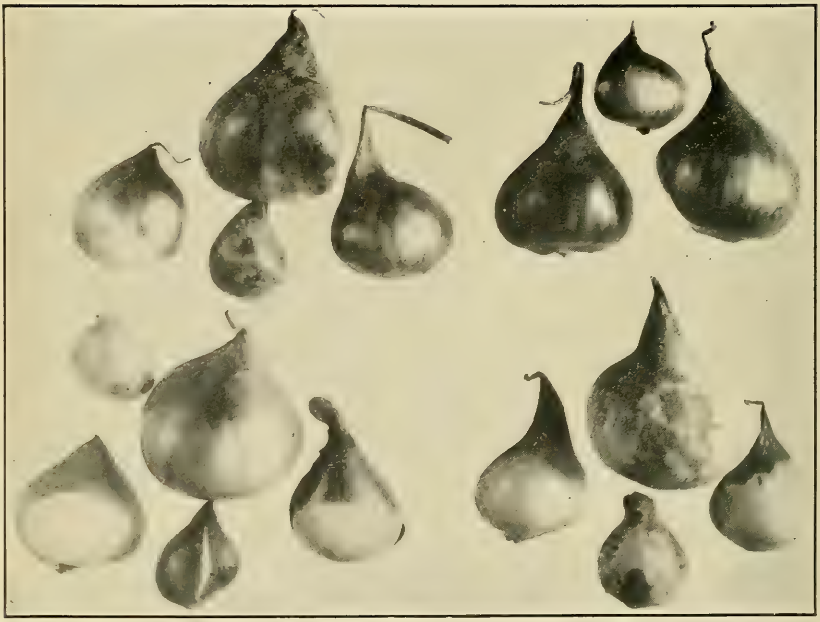


FIG. 2.—THE CLUMPS SHOWN IN FIGURE 1 CLEANED AND SEPARATED.

The actual performance, giving size and number of bulbs in each clump, is as follows: Upper left—one 14, one 10, one 9, one 7 centimeters; upper right—one 13, one 11, one 7 centimeters; lower left—one 14, two 10, two 7 centimeters; lower right—one 14, two 9, one 8 centimeters. Besides the mother bulbs, there are one or two in each clump that will flower next year.

PRIDE OF HAARLEM DARWIN TULIP BULBS.

never become cheap, because their production cost is relatively high. A comparison of the varieties in Plates XVIII and XIX, and an examination of the following performance tables (Tables 5, 6, and 7) will give valuable information on this point. It will be seen that between some varieties there is a difference in yield of 75 per cent or more. This is due to no accident or fault of location, but to the inherent characteristics of varieties. One is asked why Proserpine should be so expensive when it is an old, established variety. A glance at Plate XVIII, Figures 1 and 2, and its performance record will show that it is a poor reproducer and consequently the bulbs can never be cheap. Compare this with Artus (Pl. IV, Figs. 1 and 2) and Rosalind (Pl. IV, Figs. 3 and 4). In the autumn of 1919 these three varieties were planted at Bellingham, Wash., liberally, 14 to the row, mostly 8-centimeter round bulbs, but those of Proserpine averaged larger than the other two. Proserpine blossomed and made first-size bulbs with an increase of one or two, ranging from 4 to 9 centimeters each, while Rosalind also produced a first-size bulb for next year but gave three to six increase, ranging from flowering size downward.

The character of the reproduction is also a very potent factor of the cost. Some varieties produce a moderate number of large-sized bulbs as increase and others a large number of small ones. (Compare Pl. XX with Pl. V, Figs. 3 and 4.)

The popular Keizerkroon (Pl. XVIII, Figs. 3 and 4) is not by any means the easiest to grow and can never become cheap, like Artus for example.

PERFORMANCE RECORDS.

The number of bulbs sold from a given area of ground in any one year is not necessarily a measure of the grower's success in bulb culture. Many factors and conditions are to be considered, among which are the sizes planted, the sizes marketed, and the nature and quantity of the increase. The factor which should be studied most closely is the nature of the increase, commonly termed "propagation." (Compare Pl. III with Pls. IV and V and Pl. XVIII with Pls. XIX and XX.) After the merchantable stocks have been removed, there must be enough left of such sizes as will insure a similar product the following year to produce unqualified success.

In Tables 5 to 7 the results of many measurements of many varieties, made in many ways, are given in sufficient detail to enable the grower to judge of the success of the experimental production here outlined.

PROPAGATION BY ROWS.

A satisfactory unit of measurement in tulip-bulb production is not so easy to get as might be thought. One unit, and possibly as good a one as any, is a row across the 3-foot bed. Since this row is stand-

ard throughout the planting, a record of performance of bulbs in it is a record of the variety. The unit of measurement in Table 5 in each entry is the row whose length is the width of the bulb bed, or 3 feet, planted, but owing to the growth extending over into the paths the row may be considered 39 inches, and therefore comparable with the foreign beds, which are 1 meter wide.

To arrive at the propagation from the table, a calculation is necessary. The number of bulbs planted must be subtracted from the largest sizes specified in the yield columns; the remaining bulbs represent the "propagation" in sizes. In practice, this is strictly true, but from the standpoint of absolute accuracy in some cases there may be a slight error, for the reason that some of the increase may have grown to larger size than the bulbs planted.

The record is from plantings made in the autumn of 1919. The stocks planted were uniformly good.

Table 5 is largely self-explanatory. After the name of the variety is a column giving the size of the bulbs planted. The next column shows the number of bulbs planted to the row. Then follows a series of 12 vertical columns headed by figures showing in centimeters the circumference of the bulbs produced. In the horizontal spaces opposite each variety are shown the number of bulbs of each size dug from the unit row in July, 1920. The readings and calibrations were made in the field at digging time in July.

The stocks for which readings are given have been grown in the plats of the Bureau of Plant Industry continuously for the past 10 years or more, except Gretchen, which was imported in 1917.

TABLE 5.—*Propagation of tulip bulbs by rows in the Puget Sound region in 1920.*

Name of variety.	Bulbs planted.		Number of bulbs dug of each size (centimeters).											
	Size (centimeters).	Number to row.	14	13	12	11	10	9	8	7	6	5	4	3
Allard Pierson	8	14	2	2	....	7	3	....	13	8	4	8	....	7
Artus	[a]8	14	....	....	4	6	6	4	5	6	6	4	7	7
Do	7	21	....	....	....	7	5	15	....	6	....	10	5	6
Do	7	21	....	....	....	5	8	5	2	7	8	4	4	....
Do	5	35	....	....	....	....	6	9	5	12	13	7	6	9
Do	5	35	....	....	....	....	9	9	20	1	7	8	....	12
Aximensis	7	21	....	....	....	9	5	6	....	....	14	16	15	8
Do	8	14	....	....	2	2	8	11	....	11	13	12	7	....
Belle Alliance	8	14	....	....	6	7	....	1	....	....	....	3	....	....
Cardinal's Hat	[b]8	14	1	4	5	6	4	3	5	5	6	7	9	9
Do	7	21	....	....	....	6	5	8	3	....	5	5	....	11
Do	7	21	....	....	....	6	8	5	6	1	8	10	7	....
Do	7	21	....	....	....	6	7	6	9	1	4	3	7	3
Do	5	35	....	....	....	....	....	26	5	17	....	10	10	9
Do	5	35	....	....	....	....	....	15	4	16	9	7	6	....
Do	5	35	....	....	....	....	....	17	15	10	7	5	....	5
Chrysolora	8	14	....	....	....	10	....	3	1	....	....	1	....	....
Clara Butt	8	14	....	....	10	4	....	....	5	5	....	10	12	5
Do	8	14	....	1	8	4	1	....	8	14	....	6	6	....
Do	7	21	....	....	4	11	4	2	....	11	5	8	12	....

[a] An average in round numbers of 5 readings. [b] An average in round numbers of 10 readings.

TABLE 5.—*Propagation of tulip bulbs by rows in the Puget Sound region in 1920*—Contd.

Name of variety.	Bulbs planted.		Number of bulbs dug of each size (centimeters).											
	Size (centimeters).	Number to row.	14	13	12	11	10	9	8	7	6	5	4	3
Clara Butt	7	21	....	....	....	12	9	....	....	2	9	9	24	10
Do	7	21	....	....	....	11	....	9	6	13	....	10	10	15
Do	5	35	....	....	....	3	11	....	15	2	12	1	10	4
Do	5	35	....	....	....	1	14	10	10	3	....	8	6	10
Couleur Cardinal	8	14	....	....	7	....	7	1	....	3	2	....	3	....
Do	8	14	....	....	4	4	6	....	1	....	....	....	....	3
Do	7	21	....	....	....	6	7	5	....	....	....	2	....	....
Couleur Cramoisi	8	14	....	....	1	9	4	1	3	....	2	1	....	....
Do	8	14	....	....	4	6	2	....	2	....	3	....	2	....
Do	7	21	....	....	....	10	2	....	6	3	6	....	....	2
Do	7	21	....	....	2	3	....	10	6	5	5	....	....	....
Crimson King	8	14	....	....	....	6	4	3	6	6	....	....	4	....
Do	7	21	....	....	....	....	13	4	....	1	6	....	1	....
Do	7	21	....	....	2	....	8	7	3	....	2	....	....	....
Do	5	35	....	....	....	....	....	....	....	9	8	8	6	....
Dora	8	14	4	3	4	....	....	....	16	7	6	4	13	7
Do	5	35	....	....	....	6	10	8	10	1	....	....	....	5
Duchess de Parma	8	14	....	....	4	8	....	2	....	....	....	....	2	2
Do	5	35	....	....	....	5	6	7	9	....	3	4	11	3
Europe	8	14	....	....	8	....	4	2	....	1	....	3	....	....
Do	5	35	....	....	....	3	....	12	7	6	4	2	....	....
Do	7	21	....	....	4	7	....	10	1	4	5	....	3	....
Farncombe Sanders	8	14	2	5	....	5	....	6	3	6	....	4	....	3
Do	7	21	....	....	1	7	12	....	3	4	....	7	11	3
Do	5	35	....	....	....	4	10	12	7	3	8	....	9	4
Faust	7	21	....	....	....	7	6	....	8	....	....	8	6	....
Fra Angelico	8	14	....	9	2	2	4	1	....	7	7	4	5	....
Fulgens	8	14	2	....	6	6	....	....	16	17	11	5	9	4
Do	7	21	....	....	7	7	7	2	12	1	12	13	10	9
Gretchen	8	14	....	....	5	5	3	6	1	1	13	7	....	....
Do	5	35	....	....	....	1	....	9	17	7	7	26	27	8
Do	7	21	....	....	3	7	....	5	11	2	11	10	8	15
Isabella	8	14	....	....	1	7	4	2	9	10	6	3	6	....
Do	7	21	....	....	....	10	9	3	10	9	10	8	3	3
Keizerkroon	8	14	....	2	5	3	2	....	1	5	3	....	4	1
Do	8	14	....	2	3	4	4	....	2	....	....	....	....	2
Do	8	14	....	4	3	3	3	....	2	1	....	1	2	....
La Fiancée	8	14	....	2	....	4	7	....	....	....	4	....	....	4
Do	5	35	....	....	....	....	7	13	12	3	....	....	....	....
La Nuit	c 10	14	2	5	3	4	....	....	2	....	6	....	....	....
Do	5	35	....	....	5	3	5	7	7	8	8	....	6	....
La Reine	7	21	....	....	2	5	6	5	....	8	1	4	3	3
Do	5	35	....	....	....	....	....	4	7	2	5	7	9	3
Do	8	14	....	....	....	4	6	4	7	5	4	2	5	8
La Tulipe Noire	8	14	....	9	5	3	....	6	....	5	....	4	....	3
Do	7	21	....	....	5	3	8	5	....	....	2	....	5	....
Madame Krelage	7	21	....	....	7	9	5	....	....	5	9	5	4	....
Maiden's Blush	8	14	....	2	4	5	5	2	6	4	....	3	4	....
Do	7	21	....	....	2	7	7	5	....	2	....	5	....	....
Do	5	35	....	....	....	....	3	25	....	7	14	....	4	12
McKinley	8	14	....	....	3	8	....	3	4	....	3	8	....	3
Do	8	14	....	4	4	3	3	4	2	....	2	4	....	9
Do	7	21	....	....	....	2	9	8	1	1	....	....	4	8
Do	5	35	....	....	....	....	....	5	6	12	9	4	5	....
Do	5	35	....	....	1	....	....	....	3	13	11	6	4	4
Mon Trésor	8	14	....	....	3	4	....	4	....	1	....	3	....	....
Do	8	14	....	4	1	4	....	2	....	2	1	1	1	....
Do	7	21	....	....	1	6	3	5	8	....	....	4	....	....
Do	(d)	50	....	....	....	....	....	....	10	12	12	12	5	....
Painted Lady	10–12	11	....	....	4	7	....	10	....	9	....	4	6	....
Do	8	14	....	....	3	8	3	9	3	....	3	1	9	....
Do	7	21	....	....	....	6	8	8	1	3	....	10	7	6
Do	5	35	....	....	....	....	3	25	....	7	14	....	4	10
Pride of Haarlem	10	11	4	3	3	1	....	3	....	4	5	3	....	....
Do	8	14	2	3	6	3	....	....	....	....	4	7	5	4
Do	7	21	....	1	7	5	3	....	3	....	....	....	....	1
Do	5	35	....	....	5	6	9	7	7	1	....	3	....	3
Prince of Austria	8	14	....	....	7	4	2	....	1	....	5	....	2	4
Do	8	14	....	3	4	2	2	3	4	....	....	....	....	2
Do	7	21	....	....	....	9	5	....	5	....	....	5	....	4
Do	7	21	....	....	....	5	11	3	1	4	....	....	....	3
Proserpine	8	14	6	4	2	....	....	1	4	4	....	2	....	2
Psyche	8	14	5	4	2	3	....	....	5	3	....	8	5	3
Rev. H. Ewbank	8	14	....	....	7	5	2	7	....	....	....	1	3	....
Do	7	21	....	....	7	7	6	3	....	10	9	....	....	2

c These were above 10 centimeters.

d Under 5 centimeters.

TABLE 5.—*Propagation of tulip bulbs by rows in the Puget Sound region in 1920*—Contd.

Name and variety.	Bulbs planted.		Number of bulbs dug of each size (centimeters).											
	Size (centimeters).	Number to row.	14	13	12	11	10	9	8	7	6	5	4	3
Rosalind	8	14	....	....	....	2	8	4	14	9	5	7	6	....
Samuel Lover	8	14	....	....	9	5	....	1	9	8	3	3	....	3
Sieraad van Flora	8	14	....	3	7	4	....	....	....	6	....	....	8	8
Do	7	21	....	....	4	4	7	....	1	5	2	....	....	3
Do	5	35	....	....	1	....	3	16	5	7	3	....	....	4
The Sultan	8	14	....	2	3	5	4	4	....	9	....	6	....	....
Do	7	21	....	....	4	10	6	....	6	10	9	7	....	....
Do	5	35	....	....	....	....	5	24	2	10	6	9	13	3
Do	7	21	....	....	2	3	4	3	9	....	7	....	7	5
Thomas Moore	[b] 8	14	....	2	6	5	6	4	6	4	6	6	7	7
Do	7	21	....	....	1	1	11	7	....	9	....	4	....	5
Do	5	35	....	....	....	1	5	17	8	9	1	5	13	9
Do	7	21	....	....	1	10	....	6	7	9	....	3	3	2
Do	5	35	....	....	....	....	12	3	12	11	10	8	8	10
Do	7	21	....	....	....	3	7	9	8	6	....	5	7	7
Do	([d])	50	....	....	....	....	....	7	10	10	22	....	11	18
White Swan	7	21	....	1	8	7	5	....	4	....	3	12	....	5
Do	8	14	....	2	9	....	2	1	....	6	8	9	7	....
William III	5	35	....	....	....	....	6	15	10	6	....	7	10	8
Do	8	14	....	....	8	6	....	....	9	6	....	8	8	4
Yellow Prince	8	14	....	....	10	3	....	1	....	3	....	2	....	3
Do	5	35	....	....	....	....	4	8	....	8	11	1	....	....

[b] An average in round numbers of 10 readings.

[d] Under 5 centimeters.

PROPAGATION REVEALED BY THE PLANTING RECORD.

Another way of judging of the performance of tulip stocks is by a comparison of planting records from year to year. With this, of course, must be coupled the turn-off. It should be noted that it is at planting time that the bulb grower gets a count of his planting stock. He does it by getting a count of the rows planted, as described elsewhere.

Table 6 presents a résumé of the planting records of the new garden at Bellingham, Wash., for the years 1919 and 1920 for 39 varieties of tulips. It will be seen readily that the computation of a record of yield from a planting of tulips is a complicated affair. It is therefore advisable to present quite a complete record in order that the reader himself may be able to weigh the factors.

In studying Table 6 it is necessary to compare not only the totals of bulbs planted but also the relation of the sizes. To a degree this is expressed in the weights. To arrive at the complete performance of a variety the turn-off in 1920 and the discard given in the footnotes, of course, must also be considered.

In the comparison is given, first, the name of the variety and its class, then five columns headed by figures showing the number of bulbs planted to the row, which are followed by a column for the total of bulbs planted, and finally the weight of the bulbs planted in 1919. The same method of presentation is followed for 1920.

The numbers heading the five columns already mentioned govern quite definitely, except where noted, the size of bulb planted; but the method of sizing needs elucidation here in order to completely understand the reproduction and propagation.

The methods used in sizing were quite uniform. It will be noted that but few elevens were planted in 1919. This means that merchantable stock was not as a rule put back in the ground. In the sizing the conventional nesting sieves were used. Sieves of 8, 7, and 5 centimeters were nested in a hand shaker, as shown in Plate XV, Figure 1. Those bulbs caught by the 8-centimeter sieve were planted 14 to the 3-foot row, those by the 7-centimeter sieve 21 to the row, and those by the 5-centimeter sieve 35 to the row. The smallest size which passed the 5-centimeter openings in the last sieve was planted 50 to the row. In a few cases a 10-centimeter sieve was employed to take out bulbs, which were planted 11 to the row.

TABLE 6.—*Yields of 39 varieties of tulips, as shown by the planting records at Bellingham, Wash., for 1919 and 1920.*

[Symbols designating the varietal class: Br=Branching, Dar=Darwin, DE=Double Early, SE=Single Early, SL=Single Late.]

Name of variety.	Class.	1919							1920						
		Number of bulbs of each size planted.					Total planted.		Number of bulbs of each size planted.					Total planted.	
		11 to row.	14 to row.	21 to row.	35 to row.	50 to row.	Bulbs.	Weight (pounds).	11 to row.	14 to row.	21 to row.	35 to row.	50 to row.	Bulbs.	Weight (pounds).
Admiral Piet Hein [a]	Dar	....	140	168	105	150	563	8	275	112	63	35	....	485	22
Allard Pierson [b c]	Dar	1,001	280	294	210	....	1,785	....	1,430	686	924	1,575	1,400	6,015	136
Artus [d]	SE	....	3,696	14,133	12,845	14,450	45,124	582	825	....	....	....	....	825	40
Bacchus [b]	SE	....	252	100	105	....	457	18	187	126	126	105	250	794	22
Baronne de la Tonnaye [e]	Dar	....	700	609	315	....	1,624	30	77	392	525	420	950	2,364	28½
Belle Alliance [f]	SE	132	812	231	105	400	1,680	46	374	196	399	350	750	2,069	51
Blanc Bordé Pourpre [g]	DE	....	4,648	8,484	....	....	13,132	265	....	672	5,250	6,160	8,500	20,582	187
Calliope [b]	Dar	....	294	483	350	....	1,127	20	869	252	210	280	450	2,061	53
Cardinal's Hat [h]	SE	....	19,348	20,496	19,775	....	59,619	1,120	2,233	....	....	....	....	2,233	120
Clara Butt [i]	Dar	....	5,502	8,799	4,865	....	19,166	450	....	2,856	6,027	7,595	13,550	30,028	311
Cottage Maid [j]	SE	....	1,078	567	630	950	3,225	....	....	700	735	875	....	2,310	40
Couleur Cardinal [b]	SE	....	1,554	945	595	600	3,694	66	1,562	616	441	385	450	3,454	110
Couleur Cramoisi [k]	SE	....	2,464	2,352	1,575	2,100	8,491	141	....	2,268	1,722	3,010	....	7,000	111
Crimson King [l]	SE	....	1,638	2,163	1,610	1,700	7,111	113	1,650	1,134	1,407	700	....	4,891	54
Duchess de Parma [m]	SE	....	1,358	1,029	700	800	3,887	70	1,661	896	483	1,120	....	4,160	113
Eugene de la Croix [b]	Dar	....	98	84	70	....	252	5	132	112	63	70	50	427	12½
Europe [n]	Dar	154	392	1,239	630	....	2,415	50	1,056	462	336	385	750	2,989	80
Fairy Queen [b]	SL	....	294	567	350	....	1,211	20	704	518	735	350	500	2,807	63½
Fulgens [o]	SL	....	812	1,470	1,190	....	3,472	75	220	672	1,470	1,470	3,400	7,232	88
Isabella [b]	SL	....	1,106	609	770	....	2,485	51	1,628	602	1,008	980	1,650	5,868	133
La Fiancée [b]	Dar	....	112	105	140	....	357	6	187	112	42	....	50	391	15
Marconi [b]	Dar	....	168	252	350	....	770	12	572	154	147	105	250	1,228	39½
McKinley [p]	SE	....	4,046	3,738	3,465	4,300	15,549	215	3,597	2,576	2,142	3,150	5,200	16,665	355
Mons. S. Mottet [b q]	Br.	66	84	42	70	100	362	8	77	70	126	175	150	598	11
Painted Lady [r]	Dar	154	140	252	245	250	1,041	19	66	350	378	280	....	1,074	25
Parisian Yellow [b]	SL	....	196	84	105	....	385	9	154	84	63	105	100	506	14
Pierre Loti [b s]	Dar	....	392	399	315	....	1,106	22	759	266	231	175	350	1,781	67
Proserpine [b]	SE	....	[t] 504	63	140	....	707	....	440	126	147	70	350	1,133	38
Psyche [b]	Dar	....	378	189	350	....	917	37	671	196	399	210	300	1,776	56
Remembrance [u]	Dar	....	126	651	455	....	1,232	24	110	392	378	175	400	1,455	30
Rev. H. Ewbank [b]	Dar	....	154	273	245	....	672	12	495	182	210	140	250	1,277	35
Sieraad van Flora [b]	Dar	....	392	252	210	....	854	21	561	154	147	105	300	1,267	46½
Sir Joseph Hooker [b]	Dar	....	126	42	35	....	203	4	132	70	....	105	100	407	9½
The Sultan [v]	Dar	....	2,212	5,880	1,015	....	9,107	167	649	2,198	2,940	....	....	5,787	60

Thomas Moore [w]	SE	....	5,950	5,313	3,465	7,150	21,878	325	1,716	602	504	1,050	1,300	5,172	....
Titian [b] [x]	DE	....	[y] 322	189	105	100	716	14	187	252	189	105	200	933	23
Vuurbaak [b] [z]	DE	....	[y] 560	189	140	....	889	38	682	210	189	175	300	1,556	54
Wedding Veil [b]	Dar	....	98	210	245	....	553	10	220	266	84	70	250	890	22
William III [b]	DE	....	280	273	735	....	1,288	26	594	378	294	245	750	2,261	54½

[a] Note the relative increase in size, a large increase in weight, but an actual decrease in the number of bulbs, probably due to a large number of the fifties failing to grow and there being little or no reproduction in the small sizes planted.

[b] All the stock planted.

[c] Contains one lot of 1,091 bulbs imported in 1919 and planted late.

[d] A total of 22,800 bulbs were turned off, an endeavor being made to pick out all that would flower. Many small, scarcely merchantable bulbs were therefore included. The nonflowering stock to the extent of 50,400 bulblets, weighing 448 pounds, was discarded. These were nearly all under 8 cm. in circumference.

[e] A total of 900 bulbs, above 10 cm. in circumference were disposed of, weighing 59 pounds.

[f] A total of 450 bulbs were marketed, weighing 24 pounds. This record is of one lot only.

[g] A total of 11,000 bulbs were disposed of, weighing 427 pounds; yield very poor for this variety on account of bad drainage.

[h] The turn-off was 50,000 bulbs and included all bulbs which would flower. They weighed 1,801 pounds. The discarded small bulbs, mostly 8 cm. and under, weighed 500 pounds and numbered about 50,000 also.

[i] Disposed of 15,000 bulbs, weighing 736 pounds. Compare Figures 3 and 4, Plate V.

[j] The bulbs planted in 1919 were dug as soon as flowers had faded and were therefore small and poorly developed. A total of 300 bulbs were marketed, weighing 26 pounds.

[k] A total of 3,500 bulbs disposed of, all above 10 cm.; all below 5 cm. were discarded.

[l] A total of 1,350 first-size bulbs were disposed of; all below 5 cm. were discarded.

[m] All below 5 cm. discarded and not counted or weighed.

[n] A total of 650 bulbs were marketed, weighing 40 pounds.

[o] A total of 1,500 bulbs were marketed, weighing 97 pounds.

[p] A total of 3,000 bulbs were marketed, weighing 179 pounds.

[q] Lower end of the plat was badly injured by poor drainage.

[r] A total of 400 mature bulbs were turned off, weighing 21 pounds, and all below 5 cm. were discarded.

[s] Reproduction always poor in this variety.

[t] These were larger than those normally planted as fourteens, being bulbs dug as soon as the flowers faded, and therefore not well developed for 1919 planting.

[u] A total of 400 bulbs were turned off, weighing 26 pounds.

[v] A total of 6,120 bulbs were marketed, weighing 347 pounds, and 60 pounds of small bulbs below 7 cm. were discarded.

[w] A total of 15,600 bulbs were marketed, weighing 517 pounds. These included all the bulbs which would flower out of a further discard of 14,000 bulblets under 7 cm., weighing 112 pounds.

[x] This is always a small reproducer, but very small bulbs blossom. In other words, the splits are comparatively large.

[y] Although planted as fourteens these bulbs were of larger size than those ordinarily set 14 to the row.

[z] This is probably subnormal, because the bulbs planted in 1919 were dug shortly after the flowers had faded.

RESULTS IN TERMS OF ACRE YIELDS OF MATURE BULBS.

It should be noted that the experimental acre at Bellingham, Wash., is shorter than it would be in commercial plantings on the right kind of soil. For this reason the results are conservative. The lands are approximately 400 feet long. The actual planted area on the acre consists of two plats varying from 42 to 45 feet wide and 380 feet long, the remainder of the acre being occupied by ditches, roadways, fence rows 12 feet inside of the line, etc. There are therefore on an acre 190 beds or 95 beds in each plat, each bed with its attendant path being 4 feet wide and extending across the plat.

Table 7 gives an acre-performance turn-off for two years. Records of bulbs turned off relate to merchantable stocks except where the contrary is noted. In all cases the turn-off was picked out of the stock at cleaning time by hand, and no sizing was done on it.

TABLE 7.—*Plantings and yields of merchantable tulips on 1 acre at Bellingham, Wash., in 1919 and 1920.*

Name of variety.	Bulbs of all sizes planted in the previous year.	Bulbs marketed.
Season of 1919:		
Artus	89,198	23,300
Bacchus	631	....
Bakhuis	64	....
Bizard Verdikt	4,174	800
Brutus	67	....
Cardinal's Hat	78,694	22,000
Chrysolora	488	....
Cottage Maid	5,156	1,800
Couleur Cardinal	7,593	3,694
Couleur Cramoisi	11,538	2,100
Crimson King	10,780	1,300
Duchess de Parma	9,657	2,000
Duchess of Austria	229	....
Duc van Thol	300	....
Dusart	209	....
Joost van den Vondel	438	....
Keizerkroon	9,726	2,400
King of the Yellows	1,359	....
Lac van Rhijn	3,983	400
La Reine	5,654	1,700
L'Immaculée	4,254	400
McKinley	19,348	6,400
Mon Trésor	16,878	2,500
Ophir d'Or	193	....
Pottebakker	1,080	....
Prince of Austria	9,002	4,200
Princess Marianne	8,959	2,800
Proserpine	124	....
Rosamundi Huykman	955	....
Rose Aplatie	76	....
Rose Gris de Lin	2,132	400
Thomas Moore (Pl. XVI, Fig. 3)	27,467	6,000
Titian	758	....
Van Berghem	158	....
Van der Neer	37	....
Van Gooyen	130	....
Vermilion Brilliant	877	....
Season of 1919—Continued.		
White Swan	2,429	....
Yellow Prince (Pl. XVI, Fig. 1)	5,188	2,200
Total	339,983	86,994
Season of 1920:		
Acuminata	84	....
Admiral Piet Hein	563	....
Advance	147	....
Alitz	1,176	600
Allard Pierson	784	....
Andre Doria	1,134	....
Anton Roozen	1,061	....
Apollo	63	....
Arentine	1,310	450
Artus [a]	45,124	22,800
Auber	756	....
Aurora	196	....
Aximensis	1,099	500
Bacchus	457	....
Baronne de la Tonnaye	1,624	900
Belle Alliance	1,680	450
Billietiana	994	500
Bizard Verdikt	3,663	1,450
Boule de Neige	504	300
Bridesmaid [b]	2,284	1,600
Brutus	49	....
Caledonia	1,071	500
Calliope	1,127	....
Cardinal's Hat [a]	59,619	50,000
Carinata Rubra	973	400
Carl Becker	1,029	500
Chrysolora	336	....
Clara Butt [b]	19,166	15,000
Columbus	448	....
Cottage Maid	3,225	1,100
Couleur Cardinal	3,694	....
Couleur Cramoisi	8,491	3,500

[a] In Artus, Cardinal's Hat, and Thomas Moore, an effort was made to turn off every bulb that would flower. The yield is, therefore, abnormally high. To arrive at the merchantable stocks in these varieties about 60 per cent must be deducted.

[b] In Clara Butt, The Sultan, and Bridesmaid, small flowering bulbs were also included. A deduction here of 25 per cent will leave about the proper number of merchantable bulbs.

TABLE 7.—*Plantings and yields of merchantable tulips on 1 acre at Bellingham, Wash., in 1919 and 1920*—Continued.

Name of variety.	Bulbs of all sizes planted in the previous year.	Bulbs marketed.	Name of variety.	Bulbs of all sizes planted in the previous year.	Bulbs marketed.
Season of 1920—Continued.			Season of 1920—Continued.		
Couronne d'Or	224	....	Murillo	2,031	700
Crimson King	7,111	1,350	Nauticus	833	450
Didieri	322	....	Night	679	350
Didieri lutescens	84	....	Nora Ware	1,940	700
Dora	336	....	O'Brien	287	....
Duchesse de Parma	3,887	....	Ophir d'Or	162	....
Duchess of Austria	225	....	Osmar	70	....
Duc van Thol	288	....	Osmodee	966	350
Dusart	175	....	Painted Lady	1,041	400
Edmée	357	....	Parisian Yellow	385	....
Edouard Andre	1,050	....	Patis	560	....
Elegans	203	....	Pensée Amère	854	400
Elegans rosea	434	400	Perfecta	212	....
Elegans variegata	49	....	Philip de Comines	767	....
El Toreador	14	....	Picotee	2,023	875
Eugene de la Croix	252	....	Pierre Loti	1,106	....
Europe	2,415	650	Planifolia	294	....
Fairy Queen	1,211	....	Pottebakker	211	....
Fanny	812	....	Pride of Haarlem	1,317	....
Farncombe Sanders	2,856	1,050	Prince of Austria	5,560	....
Faust	1,414	750	Princess Marianne	4,310	2,400
Fra Angelico	879	600	Prince William I	490	....
Fragrans	42	....	Professor Trelease	1,099	450
Fulgens	3,472	1,500	Proserpine	707	....
Galatea	1,029	350	Provost des Exilles	623	350
General Köhler	747	....	Psyche	917	....
Gesneriana aurantiaca	805	900	Ragout	119	....
Gesneriana spathulata			Reine Wilhelmina	196	....
major	728	....	Remembrance	1,232	400
Gizeldi	991	....	Retroflexa	924	300
Gold Cup	1,708	800	Rev. H. Ewbank	672	....
Golden Crown	2,415	1,200	Rex Rubrorum	5	....
Golden Eagle	609	....	Roi de Prusse	70	....
Golden King	763	300	Rosalind	1,904	800
Golden Queen	1,958	750	Rosamundi Huykman	679	....
Goldflake	1,141	900	Rose Aplatie	77	....
Gretchen	6,372	1,300	Rose Blanche	225	....
Heroine	623	....	Rose Gris de Lin	660	....
Hofdyk	413	....	Rubra maxima	609	....
Isabella	2,485	....	Salvator Rosa	529	....
Jassi Prince William	476	....	Samuel Lover	1,218	450
Joost van den Vondel	240	....	Sanspareil	133	....
Kaufmanniana	35	....	Sieraad van Flora	854	....
Keizerkroon [c]	6,063	4,100	Sir Joseph Hooker	203	....
La Candeur	2,198	....	Talma	315	....
La Citadelle	534	....	The Sultan [b]	9,107	6,120
Lac van Haarlem	8	....	Thomas Moore [a]	21,878	15,600
Lac van Rhijn	3,457	1,700	Titian	716	....
La Fiancée	357	....	Tournesol	805	....
La Merveille	518	300	Valentin	203	....
La Nuit	112	....	Van Berghem	98	....
La Reine	4,119	1,800	Van der Neer	14	....
La Tulipe Noire	434	250	Van Gooyen	99	....
Leonardo da Vinci	560	....	Vermilion Brilliant	1,156	....
L'Immaculée	2,364	600	Viridiflora	70	....
Lucretia	437	....	Viridiflora praecox	259	....
Maculata major	280	....	Von Jehring	532	....
Madame Krelage	553	....	Vuurbaak	1,100	....
Maiden's Blush	1,155	300	Wedding Veil	553	....
Marconi	770	....	White Swan (Pl. II, Fig. 1.)	5,350	1,500
Mary Stuart	336	....	William III	1,288	....
McKinley	15,549	3,000	Wouwerman [c]	2,099	1,900
Mina	1,358	....	Yellow Prince	2,928	....
Miss Blugbro	399	....	York and Lancaster	588	250
Mixture	....	1,800			
Mon Trésor	8,877	1,900	Total	354,930	163,845

[a] In Artus, Cardinal's Hat, and Thomas Moore, an effort was made to turn off every bulb that would flower. The yield is, therefore, abnormally high. To arrive at the merchantable stocks in these varieties about 60 per cent must be deducted.

[b] In Clara Butt, The Sultan, and Bridesmaid, small flowering bulbs were also included. A deduction here of 25 per cent will leave about the proper number of merchantable bulbs.

[c] These were bedding bulbs, dug and heeled in to ripen as soon as the flowers had faded in 1919. The reproduction was small, but the original bulbs recovered perfectly in one year, although planted 14 to the row.

The turn-off of bulbs from the acre in 1919 will be seen to total 86,994. In 1920 the turn-off totaled 163,845 bulbs, but for certain reasons it was desirable in that year to get rid of as many bulbs of some varieties as possible. Consequently, all bulbs of these varieties that would flower were disposed of. Many of these bulbs were smaller than should have been sold for anything but planting stock. Of this latter class there were, as nearly as can be estimated, 58,720. Deducting this from the total, there is a net merchantable turn-off of 105,125 bulbs from the acre in 1920.

The yield in 1920 is further slightly augmented by the fact that there were planted on the acre about 10,000 bulbs of all sizes which had been used for bedding on the grounds of the Department of Agriculture at Washington, D. C., in the spring of 1919. These, while not normal for first-quality stock, nevertheless probably gave a greater proportion of merchantable bulbs in 1920 than the average run of the Bureau of Plant Industry planting stock. The reproduction in these stocks, however, was much below normal. These relations are well brought out in the narrow ratio between the number of bulbs planted and the number turned off as merchantable in some varieties in Table 7. In Wouwerman only 2,099 were planted and 1,900 were turned off. This may necessitate reducing the total turn-off to 100,000.

Table 7 contains lists of all the varieties grown on the tested acre of ground devoted to tulips each year. The blanks opposite the varieties in the "Marketed" column indicate in practically every case that all the stock was planted back in the autumn of 1920. The 1919 list, as will be seen, is comparatively short in number of varieties and made up very largely of single earlies, which were the only stocks grown on the new place that year.

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FARM AND TERMINAL MARKET PRICES.

WHEAT, CORN, AND OATS, CROP MOVEMENT YEAR 1920-21.

By J. W. STROWBRIDGE,
Investigator in Marketing, Bureau of Agricultural Economics.

CONTENTS.

PURPOSE OF THE STUDY.

The accompanying tables, graphs, and maps were compiled for a study of the marketing of the 1920-21 wheat, corn, and oat crops, with the ultimate object of ascertaining a fair estimate of the average value per bushel of the entire crop rather than of a specified grade.

The tables have been compiled in two sections, each illustrated by graphs. One section gives cumulative data in 12 steps, each step being a complete summary from the beginning of the crop movement year to the end of the period. The other section gives monthly data compiled from the same figures as were used for the cumulative tables and each month is complete in itself. In reviewing the cumulative tables it should be remembered that all changes of the market during the period are averaged in the results.

METHOD OF COMPUTING PRICES.

That the reader may be in a position to judge for himself the worth of each of the prices used in the tables, a simple explanation of the methods of computation follows. The same methods were used for each of the grains.

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FARM PRICES.

The leading States in the production of wheat, corn, and oats were considered in compiling local or farm prices. Of the estimated crops produced in the United States for 1920–21, 10 States produced 456,000,000 bushels, or 61.5 per cent of the wheat; 9 States produced 1,811,000,000 bushels, or 57.2 per cent of the corn; and 12 States produced 775,000,000 bushels, or 71.8 per cent of the oats.

The farm price for each market represents the average of a combination of the values in those States which from their geographical position could be expected to contribute to that terminal. These States are named in the tables. Farm sale prices for the first day of each month are received by the Department of Agriculture from reporters in the several counties of the different States. Prices for each State are obtained by averaging these county returns, allowance being made for the relative importance in grain production of the various counties. This average State price is used in computing the average price for the combination of States for each market, the estimated monthly sales of the States being used as weights. To allow for changes that may occur in the farm price during any given month, the reported price for the first day of the month is added to the price reported for the first day of the following month and the result divided by two for an average price.

TERMINAL PRICES.

The four leading wheat markets in order of importance as to bulk of wheat receipts are Minneapolis, Kansas City, St. Louis, and Chicago. The leading corn and oat market is Chicago. Minneapolis, Omaha, and Kansas City are true primary grain markets, while St. Louis, Chicago, and Cincinnati should be considered as both primary and secondary markets. The terminal market prices are computed from the reported daily cash sales as published by the trade journals for these markets. The total "cars involved" for the four markets in the cumulative wheat table represent 47.6 per cent of the total receipts of wheat at these markets for the crop movement year 1920–21. All averages are weighted. All grades are included for each class price and all classes for the total average price. The prices are computed by multiplying the reported sale price per bushel by the number of cars sold at that price, totaling the number of cars and the extensions of all sales made and dividing the total of the extensions by the total number of cars.

PRICE-MAKING FACTORS.

The several prices reported for the different counties are influenced by local conditions outside of the general market, such as quality of crop, competition in buying, distance from terminal market, home consumption, etc.

A considerable part of the grain which is purchased in less than car-lot quantities is bought without any grade being specified. In a majority of cases the elevators are not equipped to handle, separately all the different grades grown in the territory. Usually, local quotations are made to cover any grain of merchantable quality that may be offered and are based upon the prevailing prices quoted for the grade of grain which the mixed lots will make.

Freight rates enter largely as a factor in determining the local market price; whether long or short haul rates apply should be considered in the study of prices paid at local points. An estimated average freight rate of 14.1 cents per 100 pounds, or 8.5 cents per bushel, would be required to move to Chicago the whole crop of wheat produced in Illinois and Indiana within a radius of 200 miles of that market. To compute this average, the production of each county within the 200-mile radius was used as the weight, the local freight rate from a central shipping point in each county as the value; the number of bushels produced in the county was multiplied by the local rate for that county, the production and the extensions for all the counties involved were added, and the total of the extensions was divided by the total production.

An approximate average freight rate of 17.3 cents per bushel for wheat can be considered in reviewing the farm and terminal prices for the Minneapolis market. Practically the same rate per 100 pounds applies to corn and oats as to wheat. The following freight rates for wheat were in effect:

	Cents per bushel.
September 20, 1921:	
Billings, Mont., to Minneapolis, Minn	27.3
Aberdeen, S. Dak., to Minneapolis, Minn	14.7
Frederick, Kans., to Kansas City, Mo	12.9
Columbia, Mo., to St. Louis, Mo	11.4
November 11, 1921:	
Minneapolis, Minn., to New York, N. Y., exports	22.5
Minneapolis, Minn., to New York, N. Y., domestic	25.8
Kansas City, Mo., to Galveston, Tex., exports	27.0
Kansas City, Mo., to Galveston, Tex., domestic	30.0
Chicago, Ill., to Boston, Mass., exports	13.5
Chicago, Ill., to Boston, Mass., domestic	19.2

GRAIN-MARKETING CHART.

The accompanying chart (fig. 1) illustrates several price-determining factors in produce marketing. A terminal market is the only outlet that can be depended upon at all times to absorb a surplus production. For this reason all comparisons are made on the basis of what the article would net if the terminal were used as the outlet. The numbers used on the chart should be considered only as examples. A separate study should be made of each area.

Area "A" represents any area producing a surplus with a terminal market as the only outlet. If based upon the terminal quotations, deducting freight and handling charges will determine the farm price in this territory. The net farm price is 45 cents as indicated on the chart.

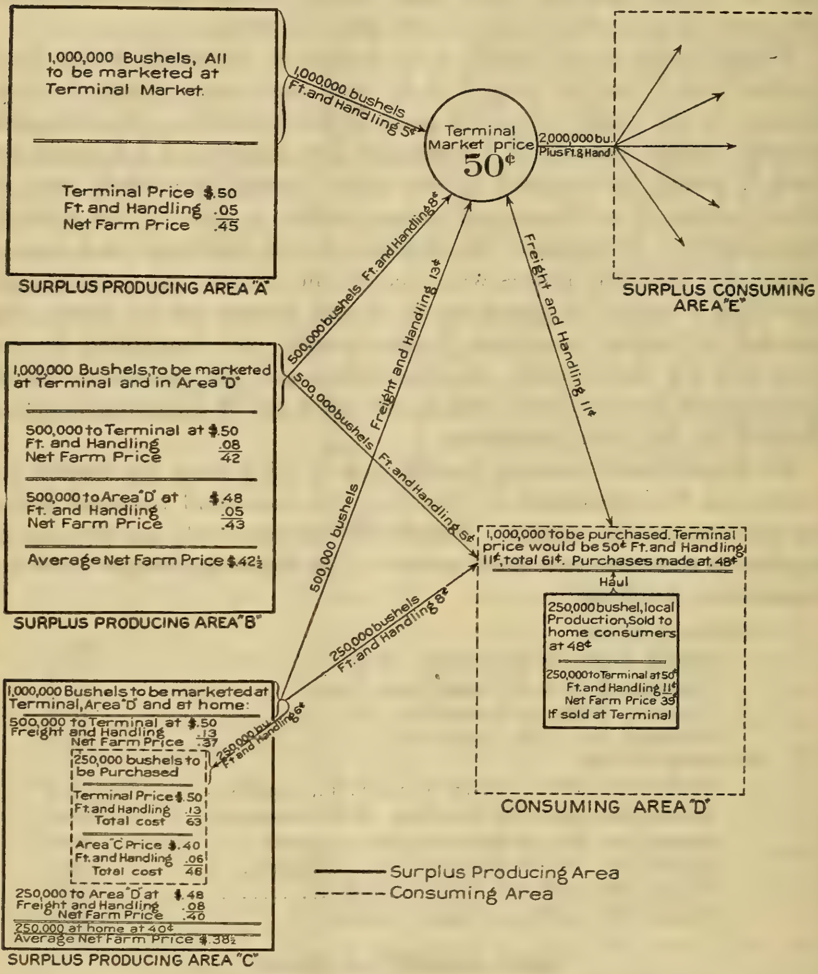

FIG. 1.—Represents five marketing conditions, one of which in some modified form will be found at each market center. Each part of the figure (area) should be considered as a separate problem; the arrows indicate its relation to the others.

Area "B" represents any area producing a surplus but without home demand and has the consuming area "D" and the terminal market for outlets. The crop of this section, if sold as indicated by the chart, would average 42½ cents per bushel net; if sold at the terminal market, the price would be 42 cents net.

Area "C" represents any area which produces a surplus and has within its boundaries a consumer's demand, either localized or scattered. This may be two farms with a surplus and one farm with a shortage; a village or city consumption or any multiple of those numbers. The crop indicated on the chart, if sold at the terminal market, would net 37 cents per bushel. By supplying the home consumer at 40 cents net, 250,000 bushels to consumers of "D" at 40 cents net and by selling the remainder of the crop at the terminal for 37 cents net, the average farm price for the crop would be 38½ cents net, a gain of 1½ cents per bushel over the terminal net price.

Area "D" represents any consuming area that produces a part of its supply within its boundaries, either localized or scattered, and depends upon outside production for the remainder of its needs. The farm price for the surplus production in this section would net 39 cents if sold at the terminal market. It can be assumed that these consumers will pay practically the same price for the home production as must be paid for supplies purchased outside, which in this case is 48 cents as indicated on the chart. By selling at home and saving the freight and handling charges, these producers will gain 9 cents per bushel over the terminal net price.

Area "E" represents the area supplied from the terminal market. The farm price for home production at the points supplied by the terminal market is usually determined from the cost of the outside supply, as at "D."

Some one of the examples cited occurs in a modified form at each market point and will account in some degree for the different farm prices reported for a State.

Under the foregoing conditions it would not be well to consider a price from any locality as representative of the amount being paid for a bushel of grain in the entire State. If the several local prices are weighted and averaged, the result will be a reasonable estimate of the average State price.

The percentage of the wheat crop moved previous to November 1, 1920, shown by the map on page 24 was the determining factor as to the high or low average of State prices. South Dakota, Nebraska, Colorado, and Utah were the only States to report a farm price of less than $2 per bushel before November 1, 1920.

Comparative table of farm and terminal sales of wheat (cumulative data).

[Per cent of total year's sales.]

July 1, 1920, to end of—	Minneapolis market.		Kansas City market.		St. Louis market.		Chicago market.	
	Reported from Montana, Minnesota, North and South Dakota.	At terminal.	Reported from Kansas, Nebraska, and Oklahoma.	At terminal.	Reported from Missouri, and Illinois.	At terminal.	Reported from Illinois and Indiana.	At terminal.
July	3.0	5.9	15.2	9.9	25.5	11.8	25.8	9.3
August	10.5	13.2	26.3	20.6	48.4	25.9	49.7	40.6
September	29.1	26.0	35.2	29.7	60.7	40.5	61.0	58.9
October	47.2	39.7	42.1	37.0	65.7	48.1	66.2	64.3
November	59.7	52.4	47.6	47.0	69.6	54.1	69.9	67.6
December	68.1	62.3	54.8	53.8	72.7	59.9	72.5	70.8
1921.								
January	73.8	70.2	62.1	63.2	76.6	66.5	76.1	73.9
February	78.7	75.3	69.2	70.5	81.5	72.9	80.4	77.1
March	83.8	81.3	74.6	77.8	86.1	79.7	85.2	84.2
April	86.9	85.2	82.2	84.0	90.2	86.2	89.7	88.9
May	92.6	90.8	91.5	91.4	95.5	93.2	95.2	94.2
June	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

REVIEW OF TABLES.

The numbers used in the comparative sales table should be considered as indexes only. The reported cash sales of wheat at Minneapolis represent about 60 per cent of the total receipts at that market. The "percentage of sales" column for each market represents the distribution of the reported cash sales for the year in cumulative form. The "percentage of sales" column for each group of States represents in cumulative form the distribution during the year of the combined estimated crop of the States named. A comparison of these tables shows a "lag" in the terminal sales behind the farm sales, especially following the beginning of the new crop movement. A part of this "lag" is accounted for in the accumulation of wheat at county elevators, which is distributed during the subsequent months. In comparing farm and terminal prices the time while in transit must be considered on all shipments.

The items under the headings, "Difference between average terminal and average farm price," should not be considered as true spreads.

For example, a car of wheat is purchased by a local dealer at Yuma, Kans., on July 30, 1921, at $0.95 per bushel. The dealer sells this car by wire, the same day, to a miller in Kansas City for $1.27 per bushel, f. o. b. Kansas City. The difference between the purchase and selling price of this car is a true "spread" as here used, for the whole transaction was completed under the same market conditions. Had this car been purchased the same day at the same

price, immediately forwarded to Kansas City and sold on arrival at the expiration of 10 days for $1.27 per bushel, the 32 cents difference in purchase and selling price would not be a true "spread," as used in this bulletin. The items under the box heads to which reference has been made are the difference between the average price paid for all wheat sold from the farms for a given period of time and the average price paid for all wheat sold at the terminal for the same period.

The Minneapolis receipts as published indicate that 14.5 per cent of the total estimated wheat crop of the United States is received at that terminal. A comparison of the tables and graphs for the four markets under consideration will show that the widest differences between farm and terminal sale prices occur at that market. The extended area from which wheat is drawn to this market should be considered in addition to other influences referred to in previous paragraphs.

The St. Louis market shows the narrowest margin between farm and terminal sales. The bulk of sales on this market is composed of Red Winter wheat and is drawn from an area comparatively near.

During October and November the farm price of wheat in Illinois and Indiana exceeded the terminal price at Chicago. These two States, while contributing only a small percentage of their crop to the Chicago market, were used as the States for comparison with that market. The movement of wheat from the counties in these States is given in per cent as follows:

	East.	West.	North.	South.
Illinois	44	6	25	25
Indiana	69	5	5	21

As 75 per cent of the Illinois crop and 95 per cent of the Indiana crop move out of the counties where grown in a direction away from Chicago, it can be assumed that the farm prices for these States are influenced by outside conditions. The graph relating to oats at Cincinnati will show that the average farm price for Michigan, Ohio, and Indiana was practically the same as the terminal price.

The cumulative tables for the combined markets show that 68.6 per cent of the total sales from the farm had been made by the end of January, 1921, at an average price of 197.1 cents per bushel. The terminals for the same period sold 67.6 per cent of their total wheat sales at an average price of 214.6 cents per bushel.

The total number of cars reported sold during the year on the four markets represents about 17 per cent of the total estimated quantity of wheat produced in the United States with a weighted average price per bushel of 193.3 cents compared with 176.1 cents, the average farm price for the 10 States used in these tables.

At the six markets mentioned in these tables, 48,348 cars of oats were sold at a weighted average price of 49 cents per bushel as against an average farm price of 45.3 cents for the 12 oat States. The average price paid at the six terminals for corn was 57.0 cents per bushel with 47.3 cents for the average farm price in the 9 corn States, At these prices the value of the three crops as estimated for the United States may be stated as follows:

Terminal sale price:	
794, 893, 000 bushels wheat at $1. 933	$1, 536, 528, 169
3, 081, 251, 000 bushels corn at .570	1, 756, 313, 070
1, 060, 737, 000 bushels oats at .490	519, 761, 130
Total value	3, 812, 602, 369
Farm sale price:	
794, 893, 000 bushels wheat at $1. 761	1, 399, 806, 573
3, 081, 251, 000 bushels corn at .473	1, 457, 431, 723
1, 060, 737, 000 bushels oats at .453	480, 513, 861
Total value	3, 337, 752, 157

The average difference between farm and terminal price per bushel on the total estimated crop of wheat is 17.2 cents; corn 9.7 cents; oats 3.7 cents, and on the combined crops 9.6 cents.

The total estimated farm value of the crop of wheat is 91.1 per cent, corn 83.0 per cent and oats 92.4 per cent of the total estimated terminal market value. The total farm value of the three crops is 87.5 per cent of the terminal value.

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21.

MINNEAPOLIS AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: Minneapolis. Cars involved.	Terminal market price: Minneapolis. Weighted average per bushel.	Farm market price: Montana, Minnesota, North and South Dakota (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Minneapolis. Cars involved.	Terminal market price: Minneapolis. Weighted average per bushel.	Farm market price: Minnesota, Montana, North and South Dakota (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
Mixed	July	55	269.2				July 1 to July 31	55	269.2			
Hard Winter		180	279.9					180	279.9			
Dark Hard Winter		13	273.2					13	273.2			
Northern Spring		241	273.9					241	273.9			
Dark Northern Spring		2,300	273.9					2,300	273.9			
Durum		434	277.2					434	277.2			
Total		3,223	274.6	240.1	3.0	34.5		3,223	274.6	240.1	3.0	34.5
Mixed	August	55	246.5				July 1 to Aug. 31	110	257.8			
Hard Winter		311	251.3					491	261.7			
Dark Hard Winter		92	258.5					105	260.3			
Northern Spring		127	249.0					368	265.2			
Dark Northern Spring		2,992	246.2					5,292	258.2			
Durum		418	247.7					852	262.7			
Total		3,995	247.1	215.7	7.5	31.4		7,218	259.4	223.3	10.5	36.1
Mixed	September	51	242.1				July 1 to Sept. 30	161	252.8			
Hard Winter		63	250.8					554	260.5			
Dark Hard Winter		304	253.1					409	254.9			
Northern Spring		83	248.1					451	262.1			
Dark Northern Spring		5,475	245.2					10,767	251.6			
Durum		980	240.5					1,832	250.8			
Total		6,956	244.9	203.6	18.6	41.3		14,174	252.3	210.8	29.1	41.5
Mixed	October	80	200.5				July 1 to Oct. 31	241	235.4			
Hard Winter		45	203.9					599	256.2			
Dark Hard Winter		429	210.1					838	231.9			
Northern Spring		172	198.3					623	244.4			
Dark Northern Spring		5,811	203.7					16,578	234.8			
Durum		927	203.5					2,759	234.9			
Total		7,464	203.9	186.7	18.1	17.2		21,638	235.9	201.2	47.2	34.7
Mixed	November	87	166.7				July 1 to Nov. 30	328	217.2			
Hard Winter		58	171.7					657	248.8			
Dark Hard Winter		370	176.2					1,208	214.9			
Northern Spring		151	170.0					774	229.9			
Dark Northern Spring		5,729	171.4					22,307	218.5			
Durum		545	181.8					3,304	226.1			
Total		6,940	172.4	150.6	12.5	21.8		28,578	220.3	190.6	59.7	29.7
Mixed	December	88	164.5				July 1 to Dec. 31	416	206.0			
Hard Winter		36	163.4					693	244.3			
Dark Hard Winter		408	169.0					1,616	203.3			
Northern Spring		115	160.8					889	221.0			
Dark Northern Spring		4,175	162.1					26,482	209.6			
Durum		560	165.3					3,864	217.3			
Total		5,382	163.0	127.2	8.4	35.8		33,960	211.2	182.4	68.1	28.8

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Wheat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Monthly table. Terminal market price: Minneapolis. Cars involved.	Monthly table. Terminal market price: Minneapolis. Weighted average per bushel.	Monthly table. Farm market price: Montana, Minnesota, North and South Dakota (combined). Weighted average per bushel.	Monthly table. Farm market price: Montana, Minnesota, North and South Dakota (combined). Per cent of total sales.	Monthly table. Difference between average terminal and average farm price.	Cumulative table. Period.	Cumulative table. Terminal market price: Minneapolis. Cars involved.	Cumulative table. Terminal market price: Minneapolis. Weighted average per bushel.	Cumulative table. Farm market price: Minnesota, Montana, North and South Dakota (combined). Weighted average per bushel.	Cumulative table. Farm market price: Minnesota, Montana, North and South Dakota (combined). Per cent of total sales.	Cumulative table. Difference between average terminal and average farm price.
	1921.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
Mixed	January	107	168.9				July 1 to Jan. 31	523	198.4			
Hard Winter		31	173.1					724	241.3			
Dark Hard Winter		107	177.4					1,723	201.7			
Northern Spring		91	169.1					980	216.2			
Dark Northern Spring		2,797	166.7					29,279	205.5			
Durum		686	169.2					4,550	210.0			
Total		3,819	167.8	130.0	5.7	37.8		37,779	206.7	178.2	73.8	28.5
Mixed	February	67	156.8				July 1 to Feb. 28	590	193.7			
Hard Winter		12	169.3					736	240.1			
Dark Hard Winter		66	170.0					1,789	200.5			
Northern Spring		74	157.3					1,054	212.0			
Dark Northern Spring		2,162	156.1					31,441	202.1			
Durum		418	154.8					4,968	205.9			
Total		2,799	156.3	131.2	4.9	25.1		40,578	203.2	175.2	78.7	28.0
Mixed	March	47	151.0				July 1 to Mar. 31	637	190.5			
Hard Winter		9	172.1					745	239.3			
Dark Hard Winter		80	169.9					1,869	199.2			
Northern Spring		81	152.3					1,135	207.8			
Dark Northern Spring		2,565	151.0					34,006	198.2			
Durum		501	150.8					5,469	200.4			
Total		3,283	151.5	127.5	5.1	24.0		43,861	199.3	172.2	83.8	27.1
Mixed	April	40	130.9				July 1 to Apr. 30	677	187.0			
Hard Winter		56	145.4					801	232.7			
Dark Hard Winter		133	148.8					2,002	195.8			
Northern Spring		53	133.2					1,188	204.4			
Dark Northern Spring		1,536	132.6					35,542	195.4			
Durum		283	141.3					5,752	196.5			
Total		2,101	135.1	113.9	3.1	21.2		45,962	196.5	170.1	86.9	26.3
Mixed	May	76	145.3				July 1 to May 3	753	182.8			
Hard Winter		21	153.8					822	230.7			
Dark Hard Winter		172	157.5					2,174	192.8			
Northern Spring		101	140.5					1,289	199.4			
Dark Northern Spring		2,299	143.1					37,841	192.2			
Durum		409	147.3					6,161	194.9			
Total		3,078	144.5	109.7	5.7	34.8		49,040	193.3	166.2	92.6	27.1
Mixed	June	121	140.4				July 1 to June 30	874	176.9			
Hard Winter		16	147.9					838	229.1			
Dark Hard Winter		156	160.3					2,330	190.6			
Northern Spring		167	146.7					1,456	193.4			
Dark Northern Spring		4,299	146.3					42,140	187.5			
Durum		473	139.9					6,634	190.1			
Total		5,232	146.0	112.2	7.4	33.8		54,272	188.6	161.9	100.0	26.7

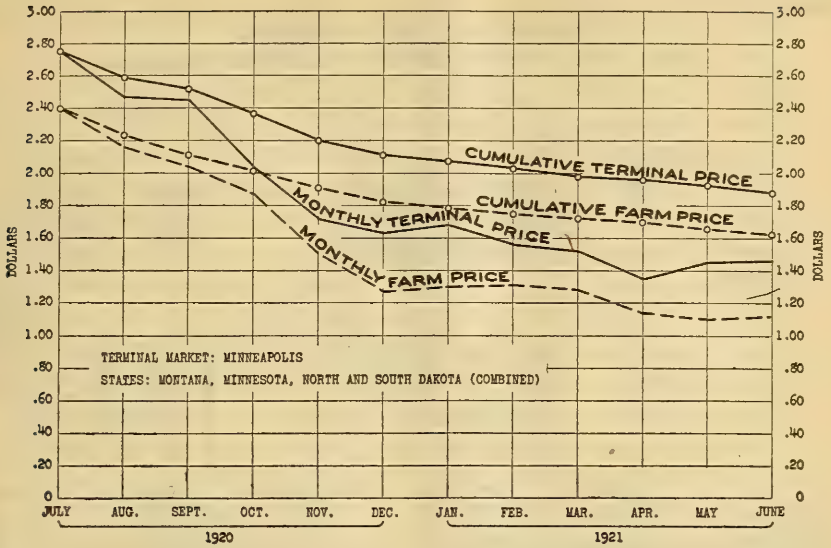

FIG. 2.—Wheat: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21. The States named on this graph are in the Spring wheat area. The tables and page 1 of the text will explain titles given lines of graph.

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

KANSAS CITY AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Kansas City.		Farm market price: Kansas, Nebraska, and Oklahoma (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Kansas City.		Farm market price: Kansas, Nebraska, and Oklahoma (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
Mixed	July	348	268.8				July 1 to July 31	348	268.8			
Red Winter		734	264.0					734	264.0			
Hard Winter		2,068	267.2					2,068	267.2			
Dark Hard Winter		235	277.8					235	277.8			
Total		3,385	267.4	231.3	15.2	36.1		3,385	267.4	231.3	15.2	36.1
Mixed	August	402	245.8				July 1 to Aug. 31	750	256.4			
Red Winter		830	241.6					1,564	252.1			
Hard Winter		2,027	245.3					4,095	256.3			
Dark Hard Winter		397	254.8					632	263.3			
Total		3,656	245.6	213.8	11.1	31.8		7,041	256.0	223.9	26.3	32.1
Mixed	September	265	247.2				July 1 to Sept. 30	1,015	250.4			
Red Winter		555	252.2					2,119	252.1			
Hard Winter		1,948	242.8					6,043	251.9			
Dark Hard Winter		351	252.7					983	259.5			
Total		3,119	246.0	206.5	8.9	39.5		10,160	252.9	219.5	35.2	33.4

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

KANSAS CITY AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table. Terminal market price: Kansas City. Cars involved.	Monthly table. Terminal market price: Kansas City. Weighted average per bushel.	Monthly table. Farm market price: Kansas, Nebraska, and Oklahoma (combined). Weighted average per bushel.	Monthly table. Farm market price: Per cent of total sales.	Monthly table. Difference between average terminal and average farm prices.	Period.	Cumulative table. Terminal market price: Kansas City. Cars involved.	Cumulative table. Terminal market price: Kansas City. Weighted average per bushel.	Cumulative table. Farm market price: Kansas, Nebraska, and Oklahoma (combined). Weighted average per bushel.	Cumulative table. Farm market price: Per cent of total sales.	Cumulative table. Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
Mixed	October	150	207.7				July 1 to Oct. 31	1,165	248.0			
Red Winter	October	284	215.3				July 1 to Oct. 31	2,403	247.7			
Hard Winter	October	1,827	204.2				July 1 to Oct. 31	7,870	240.8			
Dark Hard Winter	October	243	213.3				July 1 to Oct. 31	1,226	250.3			
Total	October	2,504	206.6	188.7	6.9	17.9	July 1 to Oct. 31	12,664	243.7	214.5	42.1	29.2
Mixed	November	168	176.2				July 1 to Nov. 30	1,333	239.0			
Red Winter	November	310	192.6				July 1 to Nov. 30	2,713	241.4			
Hard Winter	November	2,650	173.9				July 1 to Nov. 30	10,520	224.0			
Dark Hard Winter	November	304	181.1				July 1 to Nov. 30	1,530	236.5			
Total	November	3,432	176.3	152.8	5.5	23.5	July 1 to Nov. 30	16,096	229.4	207.6	47.6	21.8
Mixed	December	169	173.1				July 1 to Dec. 31	1,502	230.9			
Red Winter	December	276	187.5				July 1 to Dec. 31	2,989	236.4			
Hard Winter	December	1,579	166.7				July 1 to Dec. 31	12,099	216.5			
Dark Hard Winter	December	283	171.4				July 1 to Dec. 31	1,813	226.4			
Total	December	2,307	170.2	137.7	7.2	32.5	July 1 to Dec. 31	18,403	221.9	198.5	54.8	23.4
	1921.											
Mixed	January	265	173.5				July 1 to Jan. 31	1,767	222.8			
Red Winter	January	382	188.0				July 1 to Jan. 31	3,371	230.9			
Hard Winter	January	2,241	170.3				July 1 to Jan. 31	14,340	209.3			
Dark Hard Winter	January	317	173.6				July 1 to Jan. 31	2,130	218.5			
Total	January	3,205	173.0	142.2	7.3	30.8	July 1 to Jan. 31	21,608	214.7	192.2	52.1	22.5
Mixed	February	234	165.4				July 1 to Feb. 28	2,001	216.1			
Red Winter	February	441	177.7				July 1 to Feb. 28	3,812	224.8			
Hard Winter	February	1,600	160.8				July 1 to Feb. 28	15,940	204.4			
Dark Hard Winter	February	221	165.4				July 1 to Feb. 28	2,351	213.5			
Total	February	2,496	164.6	140.9	7.1	23.7	July 1 to Feb. 28	24,104	209.5	187.4	69.2	22.1
Mixed	March	223	152.2				July 1 to Mar. 31	2,224	209.7			
Red Winter	March	214	154.5				July 1 to Mar. 31	4,026	221.0			
Hard Winter	March	1,758	153.9				July 1 to Mar. 31	17,698	199.4			
Dark Hard Winter	March	308	160.3				July 1 to Mar. 31	2,659	207.3			
Total	March	2,503	154.6	133.5	5.4	21.1	July 1 to Mar. 31	26,607	204.3	183.4	74.6	20.9
Mixed	April	205	132.2				July 1 to Apr. 30	2,429	203.2			
Red Winter	April	192	131.1				July 1 to Apr. 30	4,218	216.9			
Hard Winter	April	1,396	132.4				July 1 to Apr. 30	19,094	194.5			
Dark Hard Winter	April	367	139.6				July 1 to Apr. 30	3,026	199.1			
Total	April	2,160	133.5	116.5	7.6	17.0	July 1 to Apr. 30	28,767	199.0	177.1	82.2	21.9
Mixed	May	205	143.0				July 1 to May 31	2,634	198.5			
Red Winter	May	238	151.2				July 1 to May 31	4,456	213.4			
Hard Winter	May	1,567	146.4				July 1 to May 31	20,661	190.8			
Dark Hard Winter	May	527	150.8				July 1 to May 31	3,553	191.9			
Total	May	2,537	147.5	115.3	9.3	32.2	July 1 to May 31	31,304	194.8	170.9	91.5	23.9
Mixed	June	301	135.9				July 1 to June 30	2,935	192.1			
Red Winter	June	297	140.0				July 1 to June 30	4,753	208.8			
Hard Winter	June	1,841	137.6				July 1 to June 30	22,502	186.5			
Dark Hard Winter	June	435	151.1				July 1 to June 30	3,988	187.5			
Total	June	2,874	139.7	114.9	8.5	24.8	July 1 to June 30	34,178	190.2	166.3	100.0	23.9

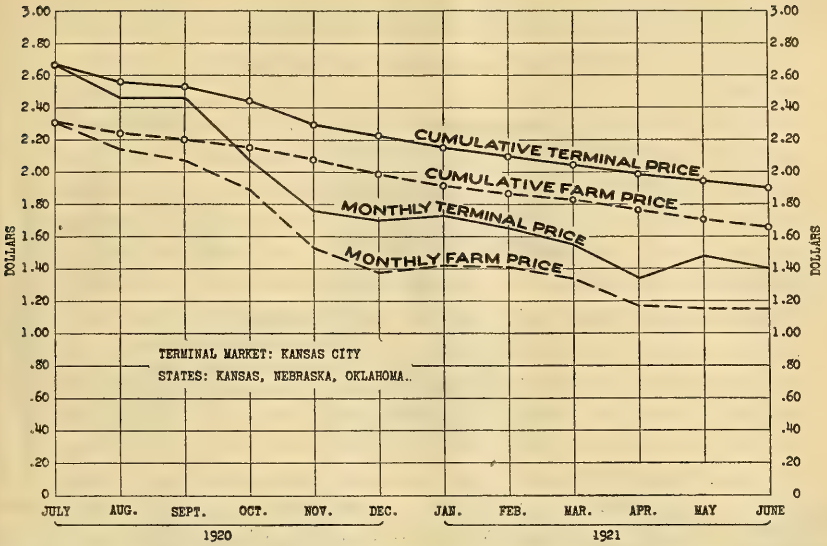

FIG. 3.—Wheat: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21. Kansas City is the largest Hard Winter Wheat market in the United States.

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

ST. LOUIS AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: St. Louis. Cars involved.	Terminal market price: St. Louis. Weighted average per bushel.	Farm market price: Missouri and Illinois (combined). Weighted average per bushel.	Farm market price: Missouri and Illinois (combined). Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: St. Louis. Cars involved.	Terminal market price: St. Louis. Weighted average per bushel.	Farm market price: Missouri and Illinois (combined). Weighted average per bushel.	Farm market price: Missouri and Illinois (combined). Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents
Mixed	July	23	271.8				July 1 to July 31.	23	271.8			
Red Winter		1,034	273.4					1,034	273.4			
Hard winter		121	273.1					121	273.1			
Total		1,178	273.3	247.2	25.5	26.1		1,178	273.3	247.2	25.5	26.1
Mixed	August	74	249.8				July 1 to Aug. 31.	97	255.0			
Red Winter		1,085	249.9					2,117	261.3			
Hard Winter		244	249.7					365	257.4			
Total		1,403	249.9	231.3	22.9	18.6		2,581	260.5	239.7	48.4	20.8
Mixed	September	188	251.8				July 1 to Sept. 30	285	258.6			
Red Winter		940	257.6					3,059	260.2			
Hard Winter		320	240.6					685	254.2			
Total		1,448	253.1	224.9	12.3	28.2		4,029	258.6	236.7	60.7	21.9

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

ST. LOUIS AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table. Terminal market price: St. Louis. Cars involved.	Monthly table. Terminal market price: St. Louis. Weighted average per bushel.	Monthly table. Farm market price: Missouri and Illinois (combined). Weighted average per bushel.	Monthly table. Farm market price: Missouri and Illinois (combined). Per cent of total sales.	Monthly table. Difference between average terminal and average farm prices.	Period.	Cumulative table. Terminal market price: St. Louis. Cars involved.	Cumulative table. Terminal market price: St. Louis. Weighted average per bushel.	Cumulative table. arm market price: Missouri and Illinois (combined). Weighted average per bushel.	Cumulative table. arm market price: Missouri and Illinois (combined). Per cent of total sales.	Cumulative table. Difference between average terminal and average farm price.
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
Mixed	October	109	213.5				July 1 to Oct. 31.	394	242.2			
Red Winter		452	222.1					3,511	255.3			
Hard Winter		191	215.1					876	245.7			
Total		752	219.2	212.5	5.0	6.7		4,781	252.4	234.8	65.7	17.6
Mixed	November.	53	190.4				July 1 to Nov. 30	447	236.1			
Red Winter		445	200.6					3,956	249.1			
Hard Winter		94	184.8					970	239.8			
Total		592	197.2	180.7	3.9	16.5		5,373	246.3	231.7	69.6	14.6
Mixed	December.	59	182.5				July 1 to Dec. 31.	506	229.8			
Red winter		371	197.4					4,327	244.7			
Hard Winter		150	179.4					1,120	231.7			
Total		580	191.2	163.6	3.1	27.6		5,953	241.0	228.8	72.7	12.2
	1921.											
Mixed	January.	64	182.9				July 1 to Jan. 1.	570	224.5			
Red Winter		463	200.6					4,790	240.4			
Hard Winter		123	178.6					1,243	226.4			
Total		650	194.7	167.4	3.9	27.3		6,603	236.4	225.6	76.6	10.8
Mixed	February.	63	173.8				July 1 to Feb. 28	633	219.5			
Red Winter		450	188.4					5,240	235.9			
Hard Winter		120	171.1					1,363	221.5			
Total		633	183.7	164.4	4.9	19.3		7,236	231.8	221.9	81.5	9.9
Mixed	March	60	160.1				July 1 to Mar. 31.	693	214.3			
Red Winter		464	164.6					5,704	230.1			
Hard Winter		154	162.9					1,517	215.6			
Total		678	163.8	150.1	4.6	13.7		7,914	225.9	218.1	86.1	7.8
Mixed	April	53	139.3				July 1 to Apr. 30	746	209.0			
Red Winter		492	139.9					6,196	222.9			
Hard Winter		101	139.7					1,618	210.8			
Total		646	139.8	129.3	4.1	10.5		8,560	219.5	214.1	90.2	5.4
Mixed	May	65	156.8				July 1 to May 31.	811	204.8			
Red Winter		558	156.1					6,754	217.4			
Hard Winter		74	153.6					1,692	208.3			
Total		697	155.9	124.8	5.3	31.1		9,257	214.7	209.2	95.5	5.5
Mixed	June	33	147.3				July 1 to June 30	844	202.6			
Red Winter		584	148.2					7,338	211.9			
Hard Winter		61	149.0					1,753	206.3			
Total		678	148.2	122.8	4.5	25.4		9,935	210.1	205.2	100.0	4.9

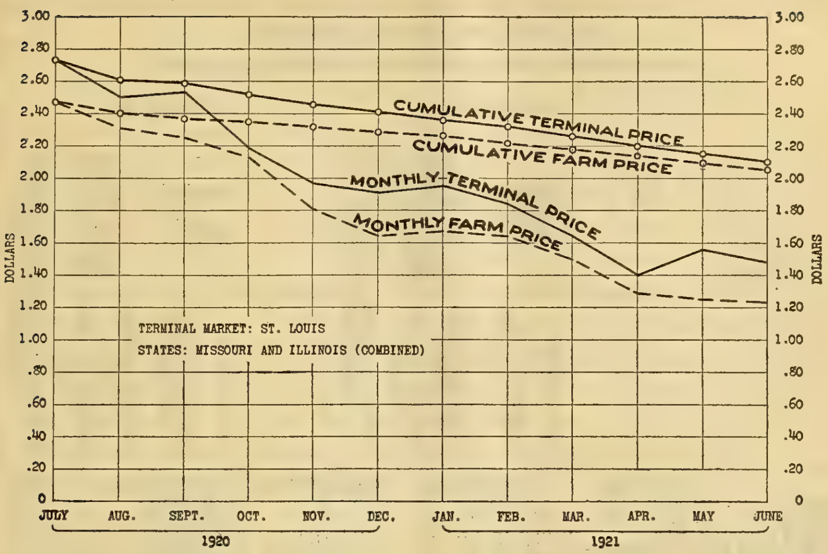

FIG. 4.—Wheat: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21. St. Louis is the central market of the Soft Red Winter wheat district.

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: Chicago. Cars involved.	Terminal market price: Chicago. Weighted average per bushel.	Farm market price: Illinois and Indiana (combined). Weighted average per bushel.	Farm market price: Illinois and Indiana (combined). Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Chicago. Cars involved.	Terminal market price: Chicago. Weighted average per bushel.	Farm market price: Illinois and Indiana (combined). Weighted average per bushel.	Farm market price: Illinois and Indiana (combined). Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
Mixed	July	82	266.2				July 1 to July 31	82	266.2			
Red Winter		270	262.2					270	262.2			
Hard Winter		363	265.2					363	265.2			
Dark Hard Winter		4	288.0					4	288.0			
Northern Spring		72	269.6					72	269.6			
Dark Northern Spring		12	275.8					12	275.8			
Total		803	264.9	245.7	25.8	19.2		803	264.9	245.7	25.8	19.2
Mixed	August	583	248.1				July 1 to Aug. 31	665	250.4			
Red Winter		603	247.3					873	251.9			
Hard Winter		1,252	249.1					1,615	252.7			
Dark Hard Winter		21	246.6					25	253.2			
Northern Spring		165	251.1					237	256.7			
Dark Northern Spring		68	255.8					80	258.8			
Total		2.692	248.8	231.5	23.9	17.3		3,495	252.5	239.0	49.7	13.5

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Chicago.		Farm market price: Illinois and Indiana (combined).		Difference between average terminal and average farm prices.	Period.	Terminal market price: Chicago.		Farm market price: Illinois and Indiana (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
Mixed	September.	455	248.5				July 1 to Sept. 30	1,120	249.5			
Red Winter		226	252.1					1,099	251.9			
Hard Winter		618	251.1					2,233	252.2			
Dark Hard Winter		19	249.6					44	251.6			
Northern Spring		162	242.6					399	250.9			
Dark Northern Spring		99	254.2					179	256.2			
Total		1,579	249.8	227.6	11.3	22.2		5,074	251.6	236.9	61.0	14.7
Mixed	October.	113	211.9				July 1 to Oct. 31	1,233	246.1			
Red Winter		45	216.5					1,144	250.5			
Hard Winter		199	212.1					2,432	248.9			
Dark Hard Winter		16	216.4					60	242.2			
Northern Spring		55	198.1					454	244.5			
Dark Northern Spring		46	200.5					225	244.8			
Total		474	209.9	212.9	5.2	− 3.0		5,548	248.1	234.9	66.2	13.2
Mixed	November.	74	186.3				July 1 to Nov. 30	1,307	242.7			
Red Winter		19	201.6					1,163	249.7			
Hard Winter		78	182.8					2,510	246.9			
Dark Hard Winter		26	175.6					86	222.1			
Northern Spring		14	180.6					468	242.6			
Dark Northern Spring		73	169.1					298	226.3			
Total		284	180.7	182.2	3.7	− 1.5		5,832	244.5	232.0	69.9	12.5
Mixed	December.	45	178.4				July 1 to Dec. 31	1,352	240.6			
Red Winter		21	196.1					1,184	248.8			
Hard Winter		58	175.6					2,568	245.3			
Dark Hard Winter		26	178.5					112	211.0			
Northern Spring		16	165.7					484	240.1			
Dark Northern Spring		111	165.9					409	209.9			
Total		277	173.4	166.9	2.6	6.5		6,109	241.5	229.6	72.5	11.9
	1921.											
Mixed	January	89	179.6				July 1 to Jan. 31	1,441	236.8			
Red Winter		17	191.7					1,201	247.9			
Hard Winter		53	177.5					2,621	243.9			
Dark Hard Winter		22	186.2					134	207.7			
Northern Spring		18	181.5					502	238.0			
Dark Northern Spring		68	171.7					477	202.3			
Total		267	178.6	170.7	3.6	7.9		6,376	238.9	226.8	76.1	12.1
Mixed	February.	56	169.7				July 1 to Feb. 28	1,497	234.3			
Red Winter		68	184.0					1,269	244.5			
Hard Winter		78	172.8					2,699	241.8			
Dark Hard Winter		5	175.8					139	206.5			
Northern Spring		12	169.2					514	234.4			
Dark Northern Spring		65	160.3					542	199.1			
Total		284	171.9	166.0	4.3	5.9		6,660	236.1	223.5	80.4	12.6

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table: Terminal market price: Chicago. Cars involved.	Monthly table: Terminal market price: Chicago. Weighted average per bushel.	Monthly table: Farm market price: Illinois and Indiana (combined). Weighted average per bushel.	Monthly table: Farm market price: Illinois and Indiana (combined). Per cent of total sales.	Monthly table: Difference between average terminal and average farm prices.	Period.	Cumulative table: Terminal market price: Chicago. Cars involved.	Cumulative table: Terminal market price: Chicago. Weighted average per bushel.	Cumulative table: Farm market price: Illinois and Indiana (combined). Weighted average per bushel.	Cumulative table: Farm market price: Illinois and Indiana (combined). Per cent of total sales.	Cumulative table: Difference between average terminal and average farm price.
	1921.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
Mixed	March	111	160.3				July 1 to Mar. 31	1,608	229.2			
Red Winter		81	163.7					1,350	239.7			
Hard Winter		241	162.6					2,940	235.3			
Dark Hard Winter		8	165.9					147	204.3			
Northern Spring		21	162.4					535	233.5			
Dark Northern Spring		152	142.3					694	186.7			
Total		614	157.3	150.6	4.8	6.7		7,274	229.4	219.3	85.2	10.1
Mixed	April	94	136.3				July 1 to Apr. 30	1,702	224.0			
Red Winter		74	141.1					1,424	234.5			
Hard Winter		178	143.1					3,118	226.9			
Dark Hard Winter		7	140.4					154	201.4			
Northern Spring		15	136.3					550	238.6			
Dark Northern Spring		34	129.4					728	184.0			
Total		402	139.7	130.0	4.5	9.7		7,676	224.7	214.9	89.7	9.8
Mixed	May	100	150.7				July 1 to May 31	1,802	220.0			
Red Winter		86	164.7					1,510	230.6			
Hard Winter		160	157.6					3,278	226.5			
Dark Hard Winter		12	162.0					166	198.6			
Northern Spring		28	150.7					578	226.9			
Dark Northern Spring		71	153.3					799	181.3			
Total		457	156.5	126.7	5.5	29.8		8,133	220.9	209.9	95.2	11.0
Mixed	June	136	124.6				July 1 to June 30	1,938	213.3			
Red Winter		114	146.1					1,624	224.6			
Hard Winter		167	150.7					3,445	222.9			
Dark Hard Winter		13	155.3					179	195.4			
Northern Spring		15	144.4					593	224.8			
Dark Northern Spring		59	151.9					858	179.2			
Total		504	142.7	124.5	4.8	18.2		8,637	216.3	205.6	100.0	10.7

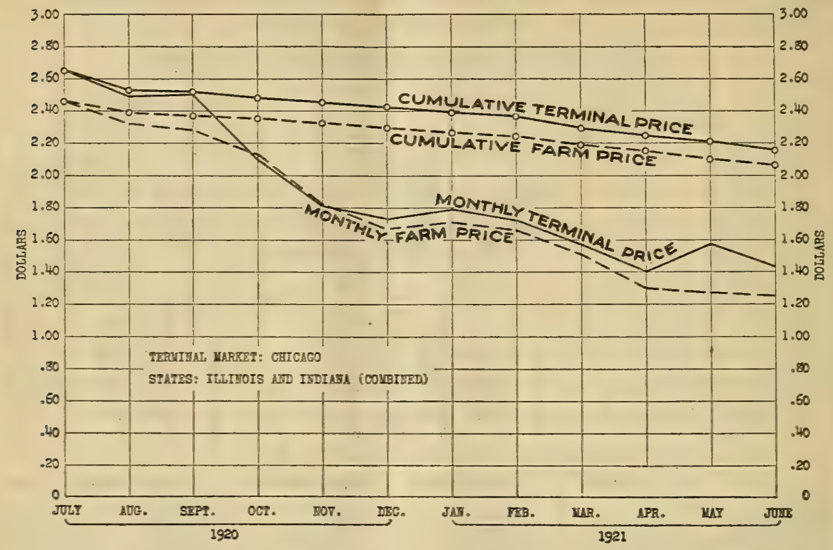

FIG. 5.—Wheat: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21. The crossing of the farm and terminal lines is explained on page 7.

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS, KANSAS CITY, ST. LOUIS, AND CHICAGO (COMBINED), AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Minneapolis, Kansas, City, St. Louis, and Chicago (combined).		Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska, Oklahoma, Montana, Minnesota, North and South Dakota (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Minneapolis, Kansas, City, St. Louis, and Chicago (combined).		Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska, Oklahoma, Montana, Minnesota, North and South Dakota (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
Mixed	July	508	268.5				July 1 to July 31	508	268.5			
Red Winter		2,038	268.5					2,038	268.5			
Hard Winter		2,732	268.0					2,732	268.0			
Dark Hard Winter		252	277.7					252	277.7			
Northern Spring		313	272.9					313	272.9			
Dark Northern Spring		2,312	273.9					2,312	273.9			
Durum		434	277.2					434	277.2			
Total		8,589	270.6	240.6	13.8	30.0		8,589	270.6	240.6	13.8	30.0

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS, KANSAS CITY, ST. LOUIS, AND CHICAGO (COMBINED), AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Terminal market price: Minneapolis, Kansas, City, St. Louis, and Chicago (combined). Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska, Oklahoma, Montana, Minnesota, North and South Dakota (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Minneapolis, Kansas, City, St. Louis, and Chicago (combined). Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska, Oklahoma, Montana, Minnesota, North and South Dakota (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
Mixed	August	1,114	247.3				July 1 to Aug. 31	1,622	253.9			
Red Winter		2,518	246.5					4,556	256.3			
Hard Winter		3,834	247.3					6,566	255.9			
Dark Hard Winter		510	255.1					762	262.6			
Northern Spring		292	250.2					605	261.9			
Dark Northern Spring		3,060	246.4					5,372	258.2			
Durum		418	247.7					852	262.7			
Total		11,746	247.3	223.1	12.4	24.2		20,335	256.9	232.1	26.2	24.8
Mixed	September.	959	248.4				July 1 to Sept. 30	2,581	251.9			
Red Winter		1,721	255.1					6,277	256.0			
Hard Winter		2,949	244.5					9,515	252.7			
Dark Hard Winter		674	252.8					1,436	258.0			
Northern Spring		245	244.5					850	256.9			
Dark Northern Spring		5,574	245.3					10,946	251.6			
Durum		980	240.5					1,832	250.8			
Total		13,102	246.6	209.2	12.4	37.4		33,437	253.1	224.5	38.6	28.6
Mixed	October	452	209.1				July 1 to Oct. 31	3,033	245.5			
Red Winter		781	219.3					7,058	251.9			
Hard Winter		2,262	205.8					11,777	243.7			
Dark Hard Winter		688	211.4					2,124	242.9			
Northern Spring		227	198.3					1,077	244.5			
Dark Northern Spring		5,857	203.7					16,803	234.9			
Durum		927	203.5					2,759	234.9			
Total		11,194	205.8	191.1	9.9	14.7		44,631	241.2	217.2	48.5	24.0
Mixed	November.	382	178.0				July 1 to Nov. 30	3,415	237.9			
Red Winter		774	197.4					7,832	246.5			
Hard Winter		2,880	174.5					14,657	230.1			
Dark Hard Winter		700	178.3					2,824	226.9			
Northern Spring		165	170.9					1,242	234.7			
Dark Northern Spring		5,802	171.4					22,605	218.6			
Durum		545	181.8					3,304	226.1			
Total		11,248	175.1	156.0	7.3	19.1		55,879	227.9	209.1	55.8	18.8
Mixed	December.	361	173.2				July 1 to Dec. 31	3,776	231.7			
Red Winter		668	193.3					8,500	242.3			
Hard Winter		1,823	168.0					16,480	223.2			
Dark Hard Winter		717	170.3					3,541	215.4			
Northern Spring		131	161.4					1,373	227.7			
Dark Northern Spring		4,286	162.2					26,891	209.6			
Durum		560	165.3					3,864	217.3			
Total		8,546	167.2	136.0	6.7	31.2		64,425	219.8	201.7	62.5	18.1

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS, KANSAS CITY, ST. LOUIS, AND CHICAGO (COMBINED), AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table. Terminal market price: Minneapolis, Kansas City, St. Louis, and Chicago (combined): Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska Oklahoma, Montana, Minnesota, North and South Dakota (combined): Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Period.	Cumulative table. Terminal market price: Minneapolis, Kansas, City, St. Louis, and Chicago (combined): Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska, Oklahoma, Montana, Minnesota, North and South Dakota (combined): Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1921.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
Mixed		525	174.7					4,301	224.8			
Red winter		862	194.8					9,362	238.0			
Hard Winter		2,448	170.9					18,928	216.4			
Dark Hard Winter		446	175.1				July 1	3,987	210.9			
Northern Spring	January	109	171.1				to	1,482	223.5			
Dark Northern Spring		2,865	166.8				Jan. 31	29,756	205.5			
Durum		686	169.2					4,550	210.0			
Total		7,941	172.4	142.7	6.1	29.7		72,366	214.6	197.1	68.6	17.5
Mixed		420	165.9					4,721	219.5			
Red Winter		959	18[illegible].2					10,321	232.9			
Hard Winter		1,810	162.1					20,738	211.7			
Dark Hard Winter		292	166.6				July 1	4,279	207.8			
Northern Spring	February.	86	159.0				to	1,568	220.0			
Dark Northern Spring		2,227	156.2				Feb. 28	31,983	202.0			
Durum		418	154.8					4,968	205.4			
Total		6,212	163.2	144.0	5.9	19.2		78,578	210.6	193.4	74.5	17.2
Mixed		441	155.2					5,162	214.0			
Red Winter		759	161.7					11,080	228.0			
Hard Winter		2,162	155.6					22,900	206.4			
Dark Hard Winter		396	162.4				July 1	4,675	204.0			
Northern Spring	March	102	154.4				to	1,670	216.0			
Dark Northern Spring		2,717	150.5				Mar. 31	34,700	198.0			
Durum		501	150.8					5,469	200.4			
Total		7,078	154.3	136.0	5.2	18.3		85,656	206.0	189.7	79.7	16.3
Mixed		392	134.0					5,554	208.4			
Red Winter		758	137.8					11,838	222.2			
Hard Winter		1,731	134.3					24,631	201.3			
Dark Hard Winter		507	142.0				July 1	5,182	197.9			
Northern Spring	April	68	133.9				to	1,738	212.8			
Dark Northern Spring		1,570	132.5				Apr. 30	36,270	195.2			
Durum		283	141.3					5,752	197.5			
Total		5,309	135.3	119.0	5.6	16.3		90,965	201.8	185.7	85.3	16.1
Mixed		446	147.1					6,000	203.8			
Red Winter		882	155.6					12,720	217.6			
Hard Winter		1,822	147.8					26,453	197.6			
Dark Hard Winter		711	152.6				July 1	5,893	192.4			
Northern Spring	May	129	142.7				to	1,867	207.9			
Dark Northern Spring		2,370	143.4				May 31	38,640	192.0			
Durum		409	147.3					6,161	194.1			
Total		6,769	147.6	115.7	7.4	31.9		97,734	198.0	180.7	92.7	17.3

Wheat prices at terminal markets, and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS, KANSAS CITY, ST. LOUIS, AND CHICAGO (COMBINED), AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Terminal market price: Minneapolis, Kansas, City, St. Louis, and Chicago (combined): Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska Oklahoma, Montana, Minnesota, North and South Dakota (combined): Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Minneapolis, Kansas, City, St. Louis, and Chicago (combined): Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Illinois, Indiana, Missouri, Kansas, Nebraska, Oklahoma, Montana, Minnesota, North and South Dakota (combined): Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1921.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
Mixed	June	591	134.9	......	....	......	July 1 to June 30	6,591	197.6	......	.....	......
Red Winter		995	145.5	......	....	......		13,715	212.4	......	.....	......
Hard Winter		2,085	139.1	......	....	......		28,538	193.3	......	.....	......
Dark Hard Winter		604	153.6	......	....	......		6,497	188.8	......	.....	......
Northern Spring		182	146.5	......	....	......		2,049	202.5	......	.....	......
Dark Northern Spring		4,358	146.4	......	....	......		42,998	187.4	......	.....	......
Durum		473	139.9	......	....	......		6,634	190.1	......	.....	......
Total		9,288	144.1	115.4	7.3	28.7		107,022	193.3	176.1	100.0	17.2

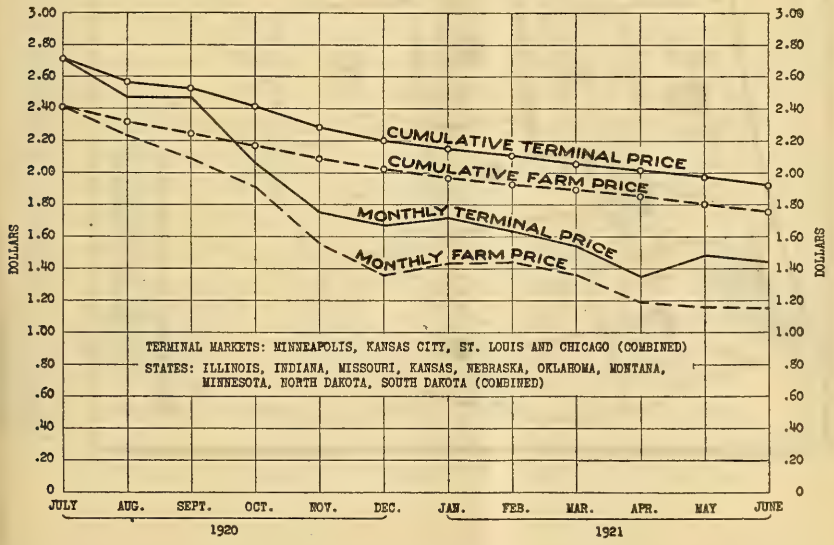

FIG. 6.—Wheat: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

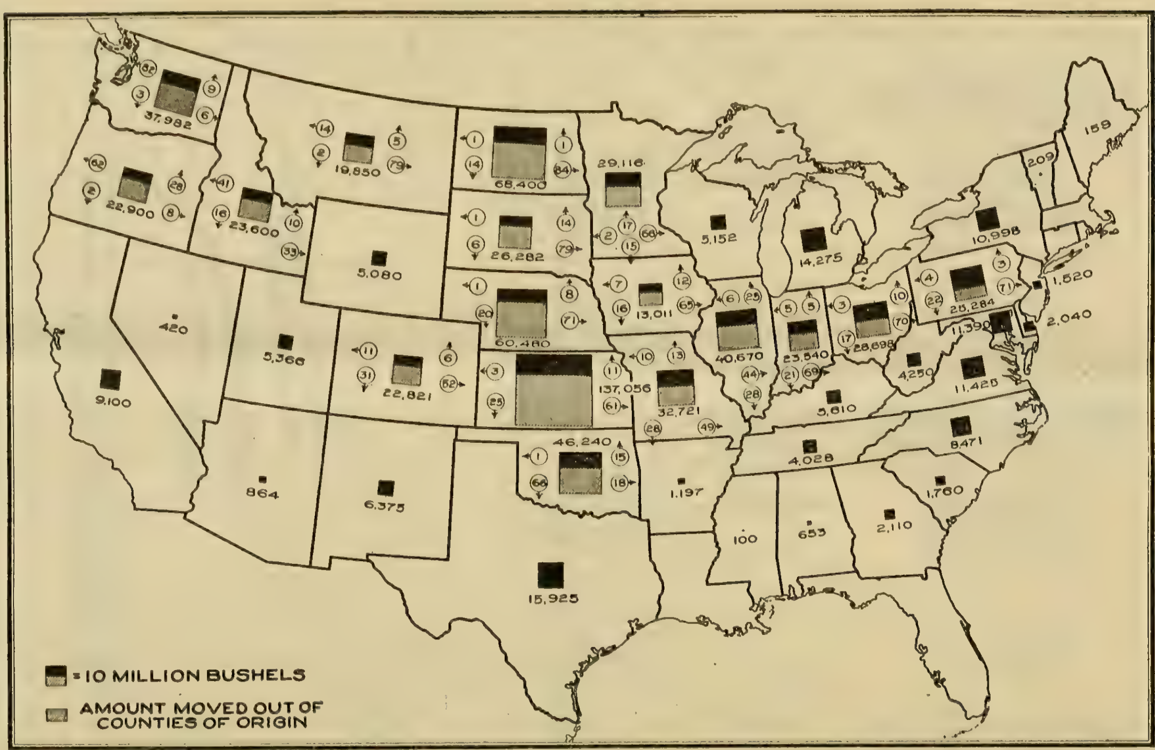

FIG. 7.—Wheat: Production and movement by States, 1920 crop. Production figures represent thousands of bushels, i. e., 000 omitted. Black portions of squares represent home consumption and the shaded portion the amount moved out of county where grown. Figures in circles represent the per cent of the crop moved out of the county where grown in the direction indicated by arrows. Movement data not available for some States.

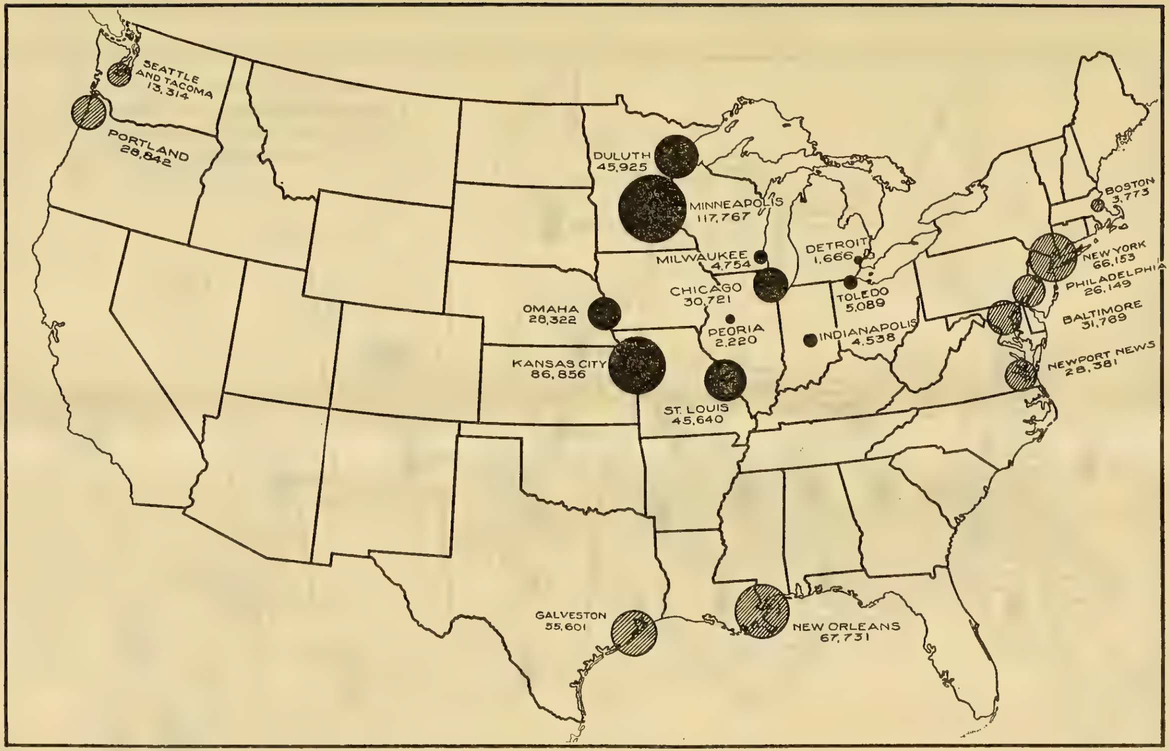

FIG. 8.—Wheat: Receipts at 11 primary and 10 seaboard markets from July 1, 1920, to June 30, 1921. Receipt figures in thousands of bushels, i. e., 000 omitted.

FIG. 9.—Wheat: Prices and sales for crop movement year 1920-21 by States. Figures in brackets indicate high and low farm prices per bushel for the year. The high price occurred in July, 1920, and the low in May following in each instance. The yearly weighted average farm price per bushel is indicated by figures outside the brackets. See page 5, regarding circles shown on map.

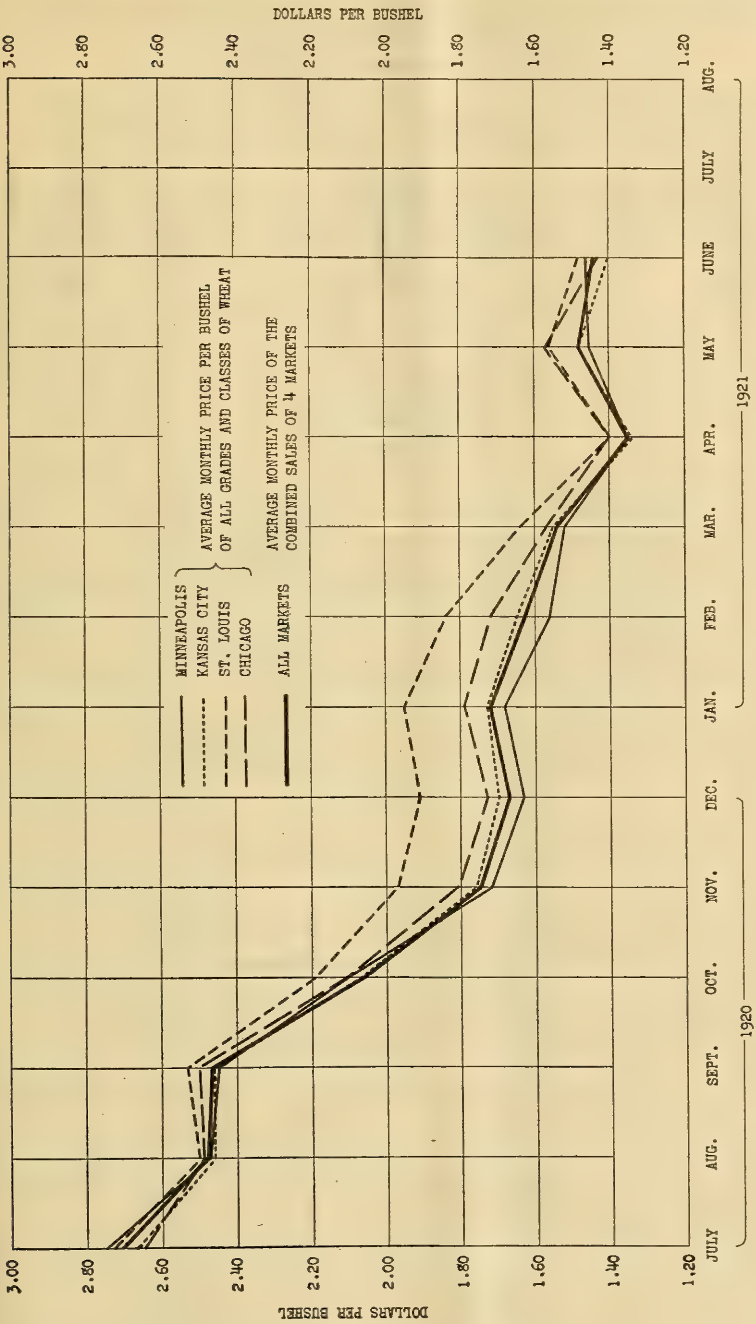

FIG. 10.—Wheat: Monthly weighted average price per bushel of all classes and grades at each of four markets and weighted average price for the combined sales of the four markets during the crop movement year 1920-21. The bulk of sales was made at Minneapolis and Kansas City, which makes those markets the controlling factors of the graph.

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21.

CHICAGO AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: Chicago. Cars involved.	Terminal market price: Chicago. Weighted average per bushel.	Farm market price: Illinois, Iowa, and Indiana (combined). Weighted average per bushel.	Farm market price: Illinois, Iowa, and Indiana (combined). Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Chicago. Cars involved.	Terminal market price: Chicago. Weighted average per bushel.	Farm market price: Illinois, Iowa, and Indiana (combined). Weighted average per bushel.	Farm market price: Illinois, Iowa, and Indiana (combined). Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	November.	380	77.3				Nov. 1 to Nov. 30	380	77.3			
Mixed		467	78.7					467	78.7			
Yellow		903	79.6					903	79.6			
Total		1,750	78.8	63.7	5.4	15.1		1,750	78.8	63.7	5.4	15.1
White	December.	446	69.7				Nov. 1 to Dec. 31	826	73.1			
Mixed		721	66.6					1,188	71.3			
Yellow		1,593	76.1					2,496	77.3			
Total		2,760	72.5	54.4	9.3	18.1		4,510	75.0	57.9	14.7	17.1
	1921.											
White	January	623	63.1				Nov. 1 to Jan. 31	1,449	68.8			
Mixed		2,407	61.7					3,595	64.8			
Yellow		3,856	62.2					6,352	68.1			
Total		6,886	62.1	51.1	14.8	11.0		11,396	67.1	54.5	29.5	12.6
White	February.	394	60.5				Nov. 1 to Feb. 28	1,843	67.2			
Mixed		1,802	59.6					5,397	63.1			
Yellow		2,217	60.2					8,569	66.0			
Total		4,413	59.9	49.8	11.3	10.1		15,809	65.2	53.2	40.8	12.0
White	March	506	60.6				Nov. 1 to Mar. 31	2,349	65.7			
Mixed		2,394	60.2					7,791	62.2			
Yellow		2,862	61.2					11,431	64.8			
Total		5,762	60.7	48.2	8.2	12.5		21,571	64.0	52.4	49.0	11.6
White	April	320	53.5				Nov. 1 to Apr. 30	2,669	64.2			
Mixed		613	54.8					8,404	61.6			
Yellow		851	54.8					12,282	64.1			
Total		1,784	54.5	47.7	4.6	6.8		23,355	63.2	52.0	53.6	11.2
White	May	769	59.3				Nov. 1 to May 31	3,438	63.1			
Mixed		699	60.9					9,103	61.1			
Yellow		1,557	62.3					13,839	63.9			
Total		3,025	61.2	49.1	10.4	12.1		26,380	62.8	51.5	64.0	11.3
White	June	1,851	54.3				Nov. 1 to June 30	5,289	60.0			
Mixed		1,345	60.3					10,448	61.4			
Yellow		2,136	62.6					15,975	63.7			
Total		5,332	59.1	48.1	9.5	11.0		31,712	62.3	51.1	73.5	11.2
White	July	804	55.2				Nov. 1 to July 31	6,093	59.8			
Mixed		887	60.5					11,335	61.3			
Yellow		1,436	61.2					17,411	63.5			
Total		3,127	59.4	49.4	5.7	10.0		34,839	62.1	51.0	79.2	11.1

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Monthly table. Terminal market price: Chicago. Cars involved.	Monthly table. Terminal market price: Chicago. Weighted average per bushel.	Monthly table. Farm market price: Illinois, Iowa, and Indiana (combined). Weighted average per bushel.	Monthly table. Farm market price: Illinois, Iowa, and Indiana (combined). Per cent of total sales.	Monthly table. Difference between average terminal and average farm price.	Cumulative table. Period.	Cumulative table. Terminal market price: Chicago. Cars involved.	Cumulative table. Terminal market price: Chicago. Weighted average per bushel.	Cumulative table. Farm market price: Illinois, Iowa, and Indiana (combined). Weighted average per bushel.	Cumulative table. Farm market price: Illinois, Iowa, and Indiana (combined). Per cent of total sales.	Cumulative table. Difference between average terminal and average farm price.
	1921.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	August	1,088	54.7	......	....	......	Nov. 1 to Aug. 31	7,181	59.0	......	......	......
Mixed		1,023	56.7	......	....	......		12,358	60.9	......	......	......
Yellow		2,260	56.7	......	....	......		19,671	62.7	......	......	......
Total		4,371	56.2	47.2	7.0	9.0		39,210	61.5	50.7	86.2	10.8
White	September.	1,455	52.8	......	....	......	Nov. 1 to Sept. 30	8,636	58.0	......	......	......
Mixed		1,877	53.0	......	....	......		14,235	59.9	......	......	......
Yellow		3,309	53.5	......	....	......		22,980	61.4	......	......	......
Total		6,641	53.2	42.4	6.8	10.8		45,851	60.3	50.1	93.0	10.2
White	October.	1,559	45.7	......	....	......	Nov. 1 to Oct. 31	10,195	56.1	......	......	......
Mixed		2,250	46.2	......	....	......		16,485	58.0	......	......	......
Yellow		3,753	46.5	......	....	......		26,733	59.3	......	......	......
Total		7,562	46.2	38.9	7.0	7.3		53,413	58.3	49.5	100.0	8.8

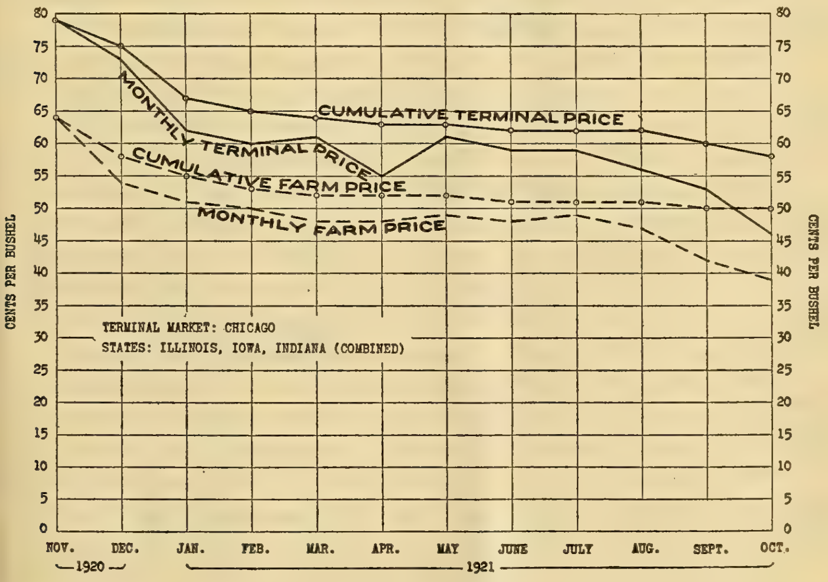

FIG. 11.—Corn: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

ST. LOUIS AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Period.	Terminal market price: St. Louis.		Farm market price: Illinois, Iowa and Missouri (combined).		Difference between average terminal and average farm prices.	Period.	Terminal market price: St. Louis.		Farm market price: Illinois, Iowa and Missouri (combined).		Difference between average terminal and average farm prices.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	November.	127	81.7	......	....	......	Nov. 1 to Nov. 30	127	81.7	......	....	......
Mixed		96	80.7	......	....	......		96	80.7	......	....	......
Yellow		248	83.0	......	....	......		248	83.0	......	....	......
Total		471	82.1	64.4	5.4	17.7		471	82.1	64.4	5.4	17.7
White	December.	172	71.4	......	....	......	Nov. 1 to Dec. 31	299	75.7	......	....	......
Mixed		3	60.0	......	....	......		99	80.0	......	....	......
Yellow		290	72.4	......	....	......		538	77.2	......	....	......
Total		465	71.9	55.1	9.4	16.8		936	77.0	58.5	14.8	18.5
	1921.											
White	January.	257	64.0	......	....	......	Nov. 1 to Jan. 31	556	70.3	......	....	......
Mixed		375	61.2	......	....	......		474	65.0	......	....	......
Yellow		697	62.0	......	....	......		1,235	68.6	......	....	......
Total		1,329	62.1	52.1	16.1	10.0		2,265	68.2	55.2	30.9	13.0
White	February.	160	62.0	......	....	......	Nov. 1 to Feb. 28	716	68.4	......	....	......
Mixed		235	61.0	......	....	......		709	63.6	......	....	......
Yellow		395	61.0	......	....	......		1,630	66.7	......	....	......
Total		790	61.2	49.3	10.3	11.9		3,055	66.4	53.7	41.2	12.7
White	March	328	61.0	......	....	......	Nov. 1 to Mar. 31	1,044	66.1	......	....	......
Mixed		272	60.0	......	....	......		981	62.6	......	....	......
Yellow		494	61.0	......	....	......		2,124	65.4	......	....	......
Total		1,094	60.7	48.3	8.2	12.4		4,149	64.9	52.8	49.4	12.1
White	April	118	57.5	......	....	......	Nov. 1 to Apr. 30	1,162	65.2	......	....	......
Mixed		105	54.4	......	....	......		1,086	61.8	......	....	......
Yellow		206	56.4	......	....	......		2,330	64.6	......	....	......
Total		429	56.2	48.2	4.2	8.0		4,578	64.1	52.5	53.6	11.6
White	May	205	56.8	......	....	......	Nov. 1 to May 31	1,367	63.9	......	....	......
Mixed		81	59.9	......	....	......		1,167	61.6	......	....	......
Yellow		408	61.5	......	....	......		2,738	64.1	......	....	......
Total		694	59.9	49.5	10.5	10.4		5,272	63.4	52.0	64.1	11.4
White	June	244	61.0	......	....	......	Nov. 1 to June 30	1,611	63.4	......	....	......
Mixed		56	57.5	......	....	......		1,223	61.4	......	....	......
Yellow		361	60.8	......	....	......		3,099	63.7	......	....	......
Total		661	60.5	49.0	9.9	11.5		5,933	63.2	51.6	74.0	11.6
White	July	235	61.7	......	....	......	Nov. 1 to July 31	1,846	63.2	......	....	......
Mixed		78	58.2	......	....	......		1,301	61.2	......	....	......
Yellow		206	60.7	......	....	......		3,305	63.5	......	....	......
Total		519	60.7	49.4	6.3	11.3		6,452	63.0	51.4	80.3	1116

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

ST. LOUIS AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table.						Cumulative table.					
	Period.	Terminal market price: Chicago.		Farm market price: Illinois, Iowa, and Missouri (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Chicago.		Farm market price: Illinois, Iowa, and Missouri (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	August	353	54.2	......	....	......	Nov. 1 to Aug. 31	2,199	61.8	......	.....	......
Mixed		113	52.4	......	....	......		1,414	60.5	......	.....	......
Yellow		315	55.1	......	....	......		3,620	62.8	......	.....	......
Total		781	54.3	46.9	7.0	7.4		7,233	62.0	51.0	87.3	11.0
White	September.	177	50.9	......	....	......	Nov. 1 to Sept. 30	2,376	60.9	......	.....	......
Mixed		112	49.8	......	....	......		1,526	59.7	......	.....	......
Yellow		387	52.5	......	....	......		4,007	61.8	......	.....	......
Total		676	51.6	41.9	6.5	9.7		7,909	61.1	50.4	93.8	10.7
White	October.	293	45.2	......	....	......	Nov. 1 to Oct. 31	2,669	59.2	......	.....	......
Mixed		178	44.7	......	....	......		1,704	58.1	......	.....	......
Yellow		385	46.0	......	....	......		4,392	60.4	......	.....	......
Total		856	45.5	42.1	6.2	3.4		8,765	59.6	49.9	100.0	9.7

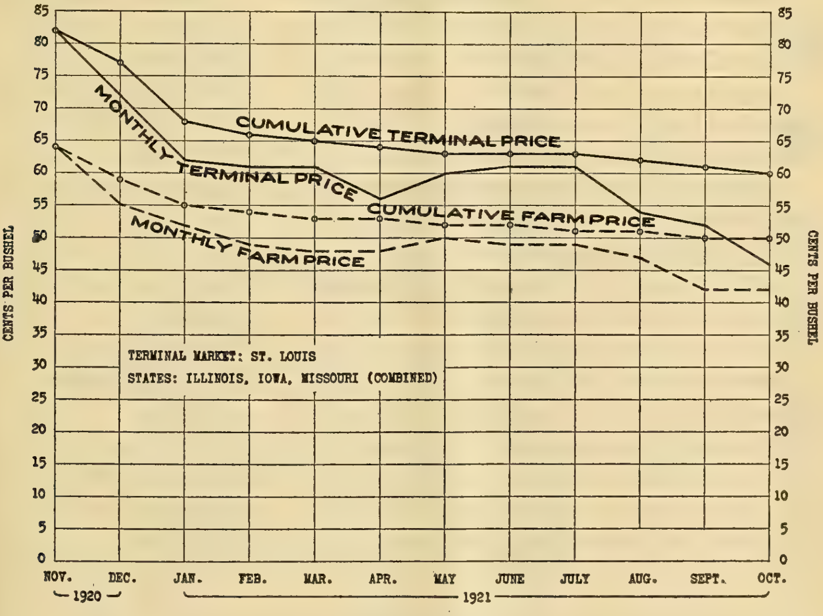

FIG. 12.—Corn: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

OMAHA AND CONTRIBUTING TERRITORY.

Class.	Month.	Monthly table. Terminal market price: Omaha. Cars involved.	Monthly table. Terminal market price: Omaha. Weighted average per bushel.	Monthly table. Farm market price: Nebraska, South Dakota, and Iowa (combined). Weighted average per bushel.	Monthly table. Farm market price: Per cent of total sales.	Monthly table. Difference between average terminal and average farm price.	Period.	Cumulative table. Terminal market price: Omaha. Cars involved.	Cumulative table. Terminal market price: Omaha. Weighted average per bushel.	Cumulative table. Farm market price: Nebraska, South Dakota, and Iowa (combined). Weighted average per bushel.	Cumulative table. Farm market price: Per cent of total sales.	Cumulative table. Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	November.	52	73.4				Nov. 1 to Nov. 30	52	73.4			
Mixed		61	68.4					61	68.4			
Yellow		118	70.8					118	70.8			
Total		231	70.7	52.6	4.1	18.1		231	70.7	52.6	4.1	18.1
White	December.	83	60.3				Nov. 1 to Dec. 31	135	65.3			
Mixed		168	59.4					229	61.7			
Yellow		200	62.0					318	65.2			
Total		451	60.7	45.4	10.2	15.3		682	64.1	47.5	14.3	16.6
	1921.											
White	January.	204	55.7				Nov. 1 to Jan. 31	339	59.5			
Mixed		431	54.6					660	57.0			
Yellow		520	54.6					838	58.6			
Total		1,155	54.7	44.3	16.6	10.4		1,837	58.2	45.8	30.9	12.4
White	February.	213	53.7				Nov. 1 to Feb. 28	552	57.8			
Mixed		346	51.6					1,006	55.2			
Yellow		416	52.1					1,254	56.4			
Total		975	52.2	41.9	12.7	10.3		2,812	56.1	44.7	43.6	11.5
White	March	248	54.6				Nov. 1 to Mar. 31	800	56.4			
Mixed		364	52.5					1,370	54.4			
Yellow		500	53.1					1,754	55.5			
Total		1,112	53.2	41.8	11.0	11.4		3,924	55.3	44.1	54.6	11.2
White	April	146	49.1				Nov. 1 to Apr. 30	946	55.3			
Mixed		162	45.8					1,532	53.5			
Yellow		212	48.4					1,966	54.7			
Total		520	47.7	37.7	4.5	10.0		4,444	54.4	43.6	59.1	10.8
White	May	257	53.8				Nov. 1 to May 31	1,203	55.0			
Mixed		192	50.7					1,724	53.2			
Yellow		375	53.1					2,341	54.4			
Total		824	52.7	38.4	8.7	14.3		5,268	54.1	42.9	67.8	11.2
White	June	207	53.4				Nov. 1 to June 30	1,410	54.7			
Mixed		204	48.8					1,928	52.7			
Yellow		318	56.9					2,659	54.7			
Total		729	53.6	41.4	10.0	12.2		5,997	54.1	42.9	77.8	11.2
White	July	152	52.6				Nov. 1 to July 31	1,562	54.5			
Mixed		161	48.2					2,089	52.4			
Yellow		223	50.6					2,882	54.4			
Total		536	50.4	41.7	5.3	8.7		6,533	53.8	42.8	83.1	11.0

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

OMAHA AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Omaha.		Farm market price: Nebraska, South Dakota, and Iowa (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Omaha.		Farm market price: Nebraska, South Dakota, and Iowa (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	August	235	45.2				Nov. 1 to Aug. 31	1,797	53.3			
Mixed		230	44.7					2,319	51.6			
Yellow		261	46.1					3,143	53.8			
Total		726	45.3	38.7	6.0	6.6		7,259	52.9	42.5	89.1	10.4
White	September	131	42.5				Nov. 1 to Sept. 30	1,928	52.5			
Mixed		170	42.4					2,489	51.0			
Yellow		263	42.8					3,406	52.9			
Total		564	42.6	34.6	5.6	8.0		7,823	52.2	42.1	94.7	10.1
White	October	140	36.1				Nov. 1 to Oct. 31	2,068	51.4			
Mixed		178	35.6					2,667	49.9			
Yellow		195	37.0					3,601	52.0			
Total		513	36.3	32.9	5.3	3.4		8,336	51.2	41.6	100.0	9.6

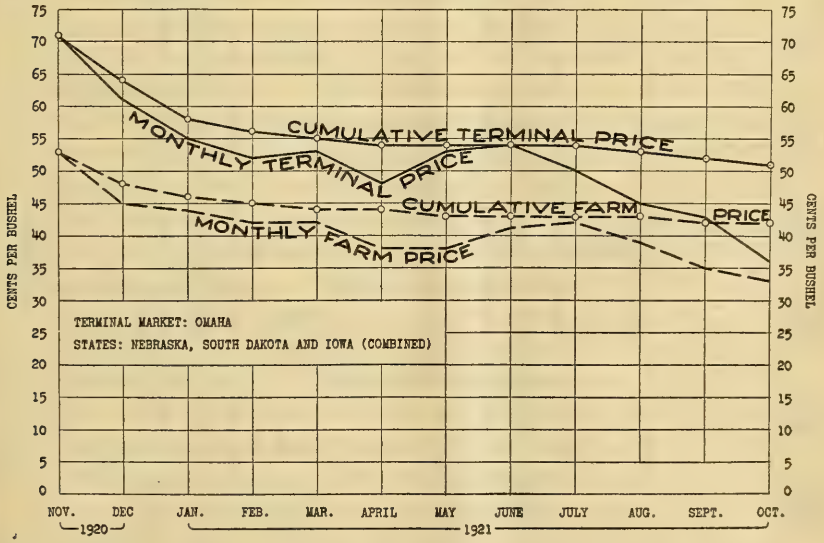

FIG 13.—Corn: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

KANSAS CITY AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Kansas City.		Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Kansas City.		Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	November.	88	69.6				Nov. 1 to Nov. 30	88	69.6			
Mixed		139	64.6					139	64.6			
Yellow		71	69.0					71	69.0			
Total		298	67.1	56.6	4.6	10.5		298	67.1	56.6	4.6	10.5
White	December.	153	65.8				Nov. 1 to Dec. 31	241	67.1			
Mixed		226	60.3					365	61.9			
Yellow		78	67.2					149	68.0			
Total		457	63.3	48.5	10.5	14.8		755	64.8	51.0	15.1	13.8
	1921.											
White	January	310	58.9				Nov. 1 to Jan. 31	551	62.5			
Mixed		453	58.0					818	59.7			
Yellow		198	59.5					347	63.1			
Total		961	58.6	47.5	17.7	11.1		1,716	61.3	48.7	32.8	12.6
White	February.	203	57.7				Nov. 1 to Feb. 28	754	61.2			
Mixed		340	56.7					1,158	58.8			
Yellow		164	57.6					511	61.3			
Total		707	57.2	44.2	12.3	13.0		2,423	60.1	47.4	45.1	12.7
White	March	340	57.8				Nov. 1 to Mar. 31	1,094	60.1			
Mixed		569	56.2					1,727	57.9			
Yellow		237	57.0					748	59.9			
Total		1,146	56.8	45.6	10.4	11.2		3,569	59.0	47.1	55.5	11.9
White	April	144	51.6				Nov. 1 to Apr. 30	1,238	59.1			
Mixed		132	50.0					1,859	57.4			
Yellow		58	53.1					806	59.4			
Total		334	51.2	41.3	4.7	9.9		3,903	58.3	46.6	60.2	11.7
White	May	176	57.5				Nov. 1 to May 31	1,414	58.9			
Mixed		146	56.0					2,005	57.2			
Yellow		98	57.6					904	59.2			
Total		420	57.0	40.6	9.1	16.4		4,323	58.2	46.2	69.3	12.0
White	June	284	58.2				Nov. 1 to June 30	1,698	58.8			
Mixed		339	53.0					2,344	56.6			
Yellow		185	56.5					1,089	58.8			
Total		808	55.6	43.8	9.9	11.8		5,131	57.8	45.6	79.2	12.2
White	July	299	55.8				Nov. 1 to July 31	1,997	58.3			
Mixed		242	47.4					2,586	55.7			
Yellow		62	55.7					1,151	58.6			
Total		603	52.4	43.3	5.0	9.1		5,734	57.2	45.4	84.2	11.8

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

KANSAS CITY AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Terminal market price: Kansas City. Cars involved.	Terminal market price: Kansas City. Weighted average per bushel.	Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Weighted average per bushel.	Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Kansas City. Cars involved.	Terminal market price: Kansas City. Weighted average per bushel.	Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Weighted average per bushel.	Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	August	181	45.9	......	....	......	Nov. 1 to Aug. 31	2,178	57.3	......	.....	......
Mixed		160	43.8	......	....	......		2,746	55.0	......	.....	......
Yellow		104	48.1	......	....	......		1,255	57.8	......	.....	......
Total		445	45.6	40.3	5.7	5.3		6,179	56.4	45.1	89.9	11.3
White	September.	59	45.1	......	....	......	Nov. 1 to Sept. 30	2,237	56.9	......	.....	......
Mixed		72	43.0	......	....	......		2,818	54.7	......	.....	......
Yellow		94	47.3	......	....	......		1,349	57.0	......	.....	......
Total		225	45.3	38.2	4.9	7.1		6,404	56.0	44.8	94.8	11.2
White	October.	172	39.4	......	....	......	Nov. 1 to Oct. 31	2,409	55.7	......	.....	......
Mixed		108	37.6	......	....	......		2,926	54.1	......	.....	......
Yellow		81	39.8	......	....	......		1,430	53.9	......	.....	......
Total		361	39.0	34.3	5.2	4.7		6,765	54.6	44.2	100.0	10.4

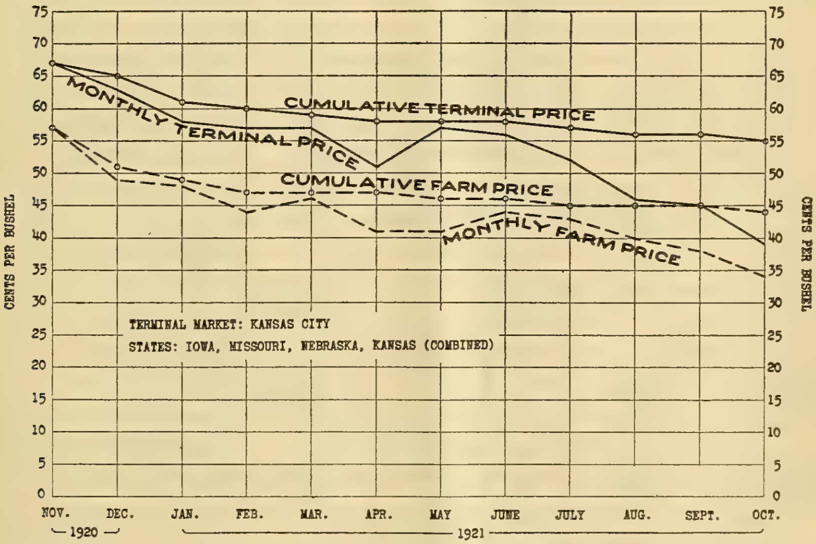

FIG. 14.—Corn: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: Minneapolis. Cars involved.	Terminal market price: Minneapolis. Weighted average per bushel.	Farm market price: Minnesota and South Dakota (combined). Weighted average per bushel.	Farm market price: Minnesota and South Dakota (combined). Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Minneapolis. Cars involved.	Terminal market price: Minneapolis. Weighted average per bushel.	Farm market price: Minnesota and South Dakota (combined). Weighted average per bushel.	Farm market price: Minnesota and South Dakota (combined). Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920-21.		Cents.	Cents.		Cents.
White	November.	22	58.8				Nov. 1 to Nov. 30	22	58.8			
Mixed		122	62.9					122	62.9			
Yellow		131	72.2					131	72.2			
Total		275	67.0	53.2	4.9	13.8		275	67.0	53.2	4.9	13.8
White	December.	51	57.8				Nov. 1 to Dec. 31	73	58.1			
Mixed		373	58.7					495	59.7			
Yellow		351	62.6					482	65.2			
Total		775	60.4	45.4	12.7	15.0		1,050	62.1	47.6	17.6	14.5
	1921.											
White	January	44	52.5				Nov. 1 to Jan. 31	117	56.0			
Mixed		511	52.4					1,006	56.0			
Yellow		571	54.8					1,053	59.5			
Total		1,126	53.6	42.9	17.7	10.7		2,176	57.7	45.1	35.3	12.6
White	February.	34	50.5				Nov. 1 to Feb. 28	151	54.7			
Mixed		312	50.3					1,318	54.6			
Yellow		255	51.0					1,308	57.8			
Total		601	50.6	36.7	14.7	13.9		2,777	56.1	43.7	50.0	12.4
White	March	34	52.4				Nov. 1 to Mar. 31	185	54.3			
Mixed		367	51.2					1,685	53.8			
Yellow		314	53.2					1,622	56.9			
Total		715	52.1	39.7	12.9	12.4		3,492	55.3	42.9	62.9	12.4
White	April	8	48.0				Nov. 1 to Apr. 30	193	54.0			
Mixed		124	46.2					1,809	53.3			
Yellow		111	48.8					1,733	56.4			
Total		243	47.4	36.9	5.1	10.5		3,735	54.8	42.4	68.0	12.4
White	May	11	52.8				Nov. 1 to May 31	204	54.0			
Mixed		127	49.8					1,936	53.1			
Yellow		122	52.7					1,855	56.2			
Total		260	51.2	38.2	6.1	13.0		3,995	54.5	42.1	74.1	12.4
White	June	43	53.6				Nov. 1 to June 30	247	53.9			
Mixed		297	50.7					2,233	52.7			
Yellow		270	52.8					2,125	55.7			
Total		610	51.8	39.8	11.1	12.0		4,605	54.2	41.8	85.2	12.4
White	July	11	50.3				Nov. 1 to July 31	258	53.7			
Mixed		117	50.1					2,350	52.6			
Yellow		95	52.9					2,220	55.6			
Total		223	51.3	38.2	3.5	13.1		4,828	54.0	41.6	88.7	12.4

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table: Terminal market price: Minneapolis. Cars involved.	Terminal market price: Minneapolis. Weighted average per bushel.	Farm market price: Minnesota and South Dakota (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Period.	Cumulative table: Terminal market price: Minneapolis. Cars involved.	Terminal market price: Minneapolis. Weighted average per bushel.	Farm market price: Minnesota and South Dakota (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	August	15	50.0	......	....	......	Nov. 1 to Aug. 31	273	53.6	......	......	......
Mixed		80	50.0	......	....	......		2,430	52.5	......	......	......
Yellow		114	51.4	......	....	......		2,334	55.4	......	......	......
Total		209	50.7	36.1	4.1	14.6		5,037	53.9	41.4	92.8	12.5
White	September.	14	47.7	......	....	......	Nov. 1 to Sept. 30	287	53.2	......	......	......
Mixed		158	46.8	......	....	......		2,588	52.2	......	......	......
Yellow		168	47.2	......	....	......		2,502	54.8	......	......	......
Total		340	47.0	33.6	3.7	13.4		5,377	53.4	41.0	96.5	12.4
White	October	16	39.7	......	....	......	Nov. 1 to Oct. 31	303	52.5	......	......	......
Mixed		189	40.2	......	....	......		2,777	51.4	......	......	......
Yellow		158	40.8	......	....	......		2,660	54.0	......	......	......
Total		363	40.4	28.7	3.5	11.7		5,740	52.6	40.6	100.0	12.0

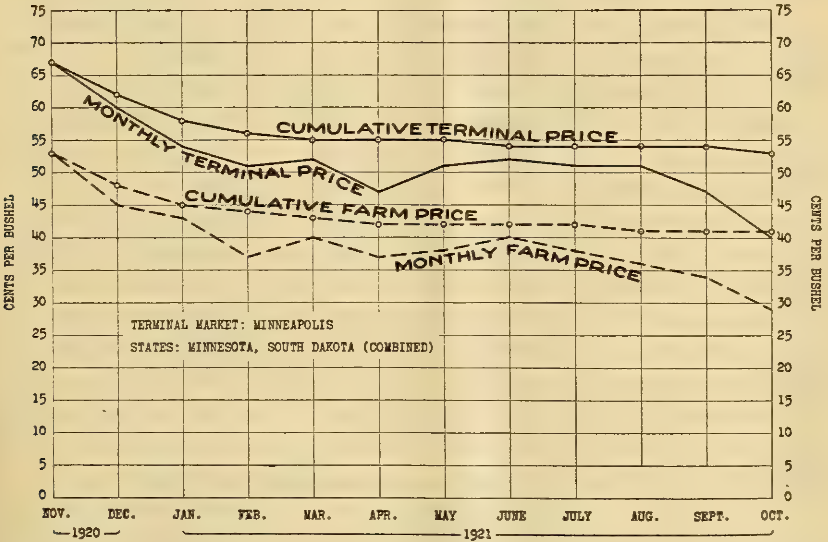

FIG. 15.—Corn: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CINCINNATI AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Cincinnati.		Farm market price: Ohio and Indiana (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Cincinnati.		Farm market price: Ohio and Indiana (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	November.	21	77.0				Nov. 1 to Nov. 30	21	77.0			
Mixed		22	82.1					22	82.1			
Yellow		18	82.2					18	82.2			
Total		61	80.3	70.9	7.6	9.4		61	80.3	70.9	7.6	9.4
White	December.	20	70.6				Nov. 1 to Dec. 31.	41	73.8			
Mixed		46	67.5					68	72.2			
Yellow		35	72.1					53	75.5			
Total		101	69.7	61.9	12.3	7.8		162	73.7	65.4	19.9	8.3
	1921.											
White	January	19	68.6				Nov. 1 to Jan. 31	60	72.2			
Mixed		38	62.1					106	68.5			
Yellow		92	66.7					145	69.9			
Total		149	65.7	59.6	13.5	6.1		311	69.9	63.0	33.4	6.9
White	February.	36	69.2				Nov. 1 to Feb. 28	96	71.0			
Mixed		36	62.8					142	67.1			
Yellow		27	64.4					172	69.0			
Total		99	65.5	56.5	12.3	9.0		410	68.8	61.3	45.7	7.5
White	March	29	65.0				Nov. 1 to Mar. 31	125	69.6			
Mixed		49	63.3					191	66.1			
Yellow		51	64.0					223	67.8			
Total		129	63.9	56.4	8.1	7.5		539	67.6	60.6	53.8	7.0
White	April	18	60.2				Nov. 1 to Apr. 30	143	68.4			
Mixed		44	56.1					235	64.2			
Yellow		51	58.6					274	66.1			
Total		113	57.8	52.9	7.1	4.9		652	65.9	59.7	60.9	6.2
White	May	24	65.2				Nov. 1 to May 31	167	67.9			
Mixed		37	62.5					272	64.0			
Yellow		49	64.4					323	65.8			
Total		110	63.9	52.9	8.7	11.0		762	65.6	58.8	69.6	6.8
White	June	37	66.9				Nov. 1 to June 30	204	67.7			
Mixed		61	62.0					333	63.6			
Yellow		58	62.9					381	65.4			
Total		156	63.4	55.0	9.2	8.4		918	65.3	58.4	78.8	6.9
White	July	29	69.5				Nov. 1 to July 31	233	68.0			
Mixed		28	62.3					361	63.5			
Yellow		26	64.1					407	65.3			
Total		83	65.3	56.3	5.1	9.0		1,001	65.3	58.2	83.9	7.1
White	August.	43	59.6				Nov. 1 to Aug. 31	276	66.6			
Mixed		28	58.8					389	63.1			
Yellow		38	60.5					445	64.9			
Total		109	59.7	57.0	5.7	2.7		1,110	64.7	58.2	89.6	6.5

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CINCINNATI AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Cincinnati.		Farm market price: Ohio and Indiana (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Cincinnati.		Farm market price: Ohio and Indiana (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1921.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	September.	50	55.9				Nov. 1 to Sept. 30	326	66.5			
Mixed		38	54.8					427	62.4			
Yellow		50	55.5					495	63.9			
Total		138	55.4	54.0	5.4	1.4		1,248	64.1	57.9	95.0	6.2
White	October	21	51.2				Nov. 1 to Oct. 13	347	65.5			
Mixed		23	50.4					450	61.8			
Yellow		28	50.9					523	63.2			
Total		72	50.8	51.0	5.0	−0.2		1,320	63.3	57.5	100.0	5.8

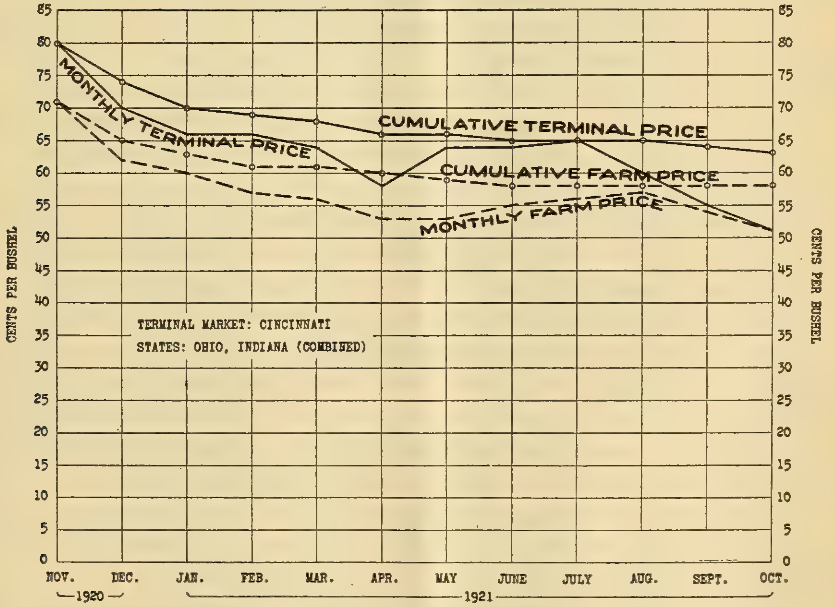

FIG. 16.—Corn: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO, ST. LOUIS, OMAHA, KANSAS CITY, MINNEAPOLIS, AND CINCINNATI (COMBINED), AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: Chicago, St. Louis, Omaha, Kansas City, Minneapolis, and Cincinnati (combined). Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Ohio, Indiana, Illinois, Minnesota, Iowa, Missouri, South Dakota, Nebraska, and Kansas (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Chicago, St. Louis, Omaha, Kansas City, Minneapolis, and Cincinnati (combined). Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Ohio, Indiana, Illinois, Minnesota, Iowa, Missouri, South Dakota, Nebraska, and Kansas (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	November.	690	76.2	......	......	......	Nov. 1 to Nov. 30	690	76.2	......	......	......
Mixed		907	74.0	......	......	......		907	74.0	......	......	......
Yellow		1,489	78.3	......	......	......		1,489	78.3	......	......	......
Total		3,086	76.6	61.7	5.6	14.9		3,086	76.6	61.7	5.6	14.9
White	December.	925	67.8	......	......	......	Nov. 1 to Dec. 31	1,615	71.3	......	......	......
Mixed		1,537	62.9	......	......	......		2,444	67.0	......	......	......
Yellow		2,547	72.3	......	......	......		4,036	74.5	......	......	......
Total		5,009	68.5	51.8	10.6	16.7		8,095	71.6	55.2	16.2	16.4
	1921.											
White	January	1,457	61.0	......	......	......	Nov. 1 to Jan. 31	3,072	66.4	......	......	......
Mixed		4,215	59.4	......	......	......		6,659	62.1	......	......	......
Yellow		5,934	60.7	......	......	......		9,970	66.2	......	......	......
Total		11,606	60.3	49.4	15.7	10.9		19,701	64.8	52.4	31.9	12.4
White	February.	1,040	58.7	......	......	......	Nov. 1 to Feb. 28	4,112	64.4	......	......	......
Mixed		3,071	57.5	......	......	......		9,730	60.7	......	......	......
Yellow		3,474	58.5	......	......	......		13,444	64.2	......	......	......
Total		7,585	58.1	46.6	11.9	11.5		27,286	62.9	50.8	43.8	12.1
White	March.	1,485	58.9	......	......	......	Nov. 1 to Mar. 31	5,597	63.0	......	......	......
Mixed		4,015	58.1	......	......	......		13,745	59.9	......	......	......
Yellow		4,458	59.5	......	......	......		17,902	63.0	......	......	......
Total		9,958	58.8	45.7	9.5	13.1		37,244	61.8	49.9	53.3	11.9
White	April.	754	53.0	......	......	......	Nov. 1 to Apr. 30	6,351	61.8	......	......	......
Mixed		1,180	52.0	......	......	......		14,725	59.3	......	......	......
Yellow		1,489	53.7	......	......	......		19,391	62.3	......	......	......
Total		3,423	52.9	44.7	5.1	8.2		40,667	61.1	49.4	58.4	11.7
White	May.	1,442	57.7	......	......	......	Nov. 1 to May 31	7,793	61.0	......	......	......
Mixed		1,282	57.6	......	......	......		16,207	59.1	......	......	......
Yellow		2,609	60.2	......	......	......		22,000	62.1	......	......	......
Total		5,333	58.9	45.7	10.1	13.2		46,000	60.8	48.9	68.5	11.9
White	June.	2,666	55.4	......	......	......	Nov. 1 to June 30	10,459	59.6	......	......	......
Mixed		2,302	56.9	......	......	......		18,509	58.9	......	......	......
Yellow		3,328	60.7	......	......	......		25,328	61.9	......	......	......
Total		8,296	57.9	46.4	9.7	11.5		54,296	60.4	48.6	78.2	11.8
White	July.	1,530	56.2	......	......	......	Nov. 1 to July 31	11,989	59.1	......	......	......
Mixed		1,513	56.2	......	......	......		20,022	58.6	......	......	......
Yellow		2,048	59.4	......	......	......		27,376	61.7	......	......	......
Total		5,091	57.5	47.3	5.4	10.2		59,387	60.1	48.5	83.6	11.6

Corn prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO, ST. LOUIS, OMAHA, KANSAS CITY, MINNEAPOLIS, AND CINCINNATI (COMBINED), AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table. Terminal market price: Chicago, St. Louis, Omaha, Kansas City, Minneapolis, and Cincinnati (combined). Cars involved.	Weighted average per bushel.	Farm market price: Ohio, Indiana, Illinois, Minnesota, Iowa, Missouri, South Dakota, Nebraska, and Kansas (combined). Weighted average per bushel.	Per cent of total sales.	Difference between average terminal and average farm price.	Period.	Cumulative table. Terminal market price: Chicago, St. Louis, Omaha, Kansas City, Minneapolis, and Cincinnati (combined). Cars involved.	Weighted average per bushel.	Farm market price: Ohio, Indiana, Illinois, Minnesota, Iowa, Missouri, South Dakota, Nebraska, and Kansas (combined). Weighted average per bushel.	Per cent of total sales.	Difference between average terminal and average farm price
	1920.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	August.	1,915	52.6				Nov. 1 to Aug 31	13,904	58.2			
Mixed		1,634	53.1					21,656	58.2			
Yellow		3,092	55.2					30,468	61.0			
Total		6,641	53.9	44.9	5.9	9.0		66,028	59.4	48.3	89.5	11.1
White	September.	1,886	51.0				Nov. 1 to Sept. 30	15,790	57.4			
Mixed		2,427	51.4					24,083	57.5			
Yellow		4,271	52.3					34,739	59.9			
Total		8,584	51.8	40.4	5.3	11.4		74,612	58.5	47.8	94.8	10.7
White	October	2,201	44.5				Nov. 1 to Oct. 31	17,991	55.8			
Mixed		2,926	44.8					27,009	56.1			
Yellow		4,600	45.7					39,339	58.3			
Total		9,727	45.2	38.5	5.2	6.7		84,339	57.0	47.3	100.0	9.7

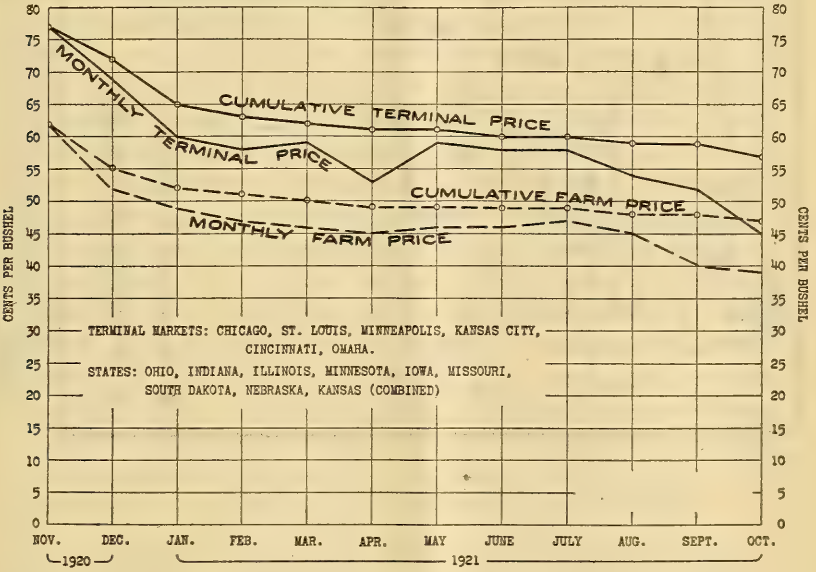

FIG. 17.—Corn: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–1921. The large Chicago sales are the controlling factors of this graph.

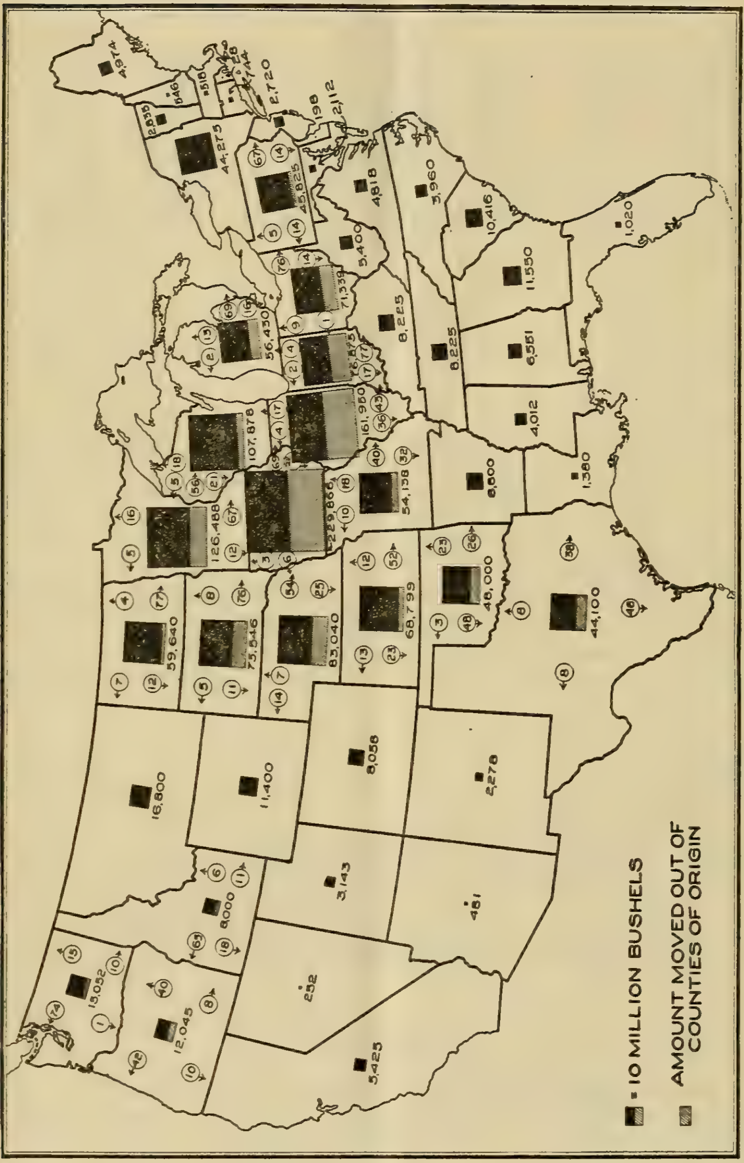

FIG. 18.—Corn: Production and movement by States, 1920 crop. Production figures represent thousands of bushels, i. e., 000 omitted. Black portions of squares represent home consumption and the shaded portions the amount moved out of county where grown. Figures in circles represent the percentage of the crop moved out of the county where grown in the direction indicated by arrows. Movement data not available for some States.

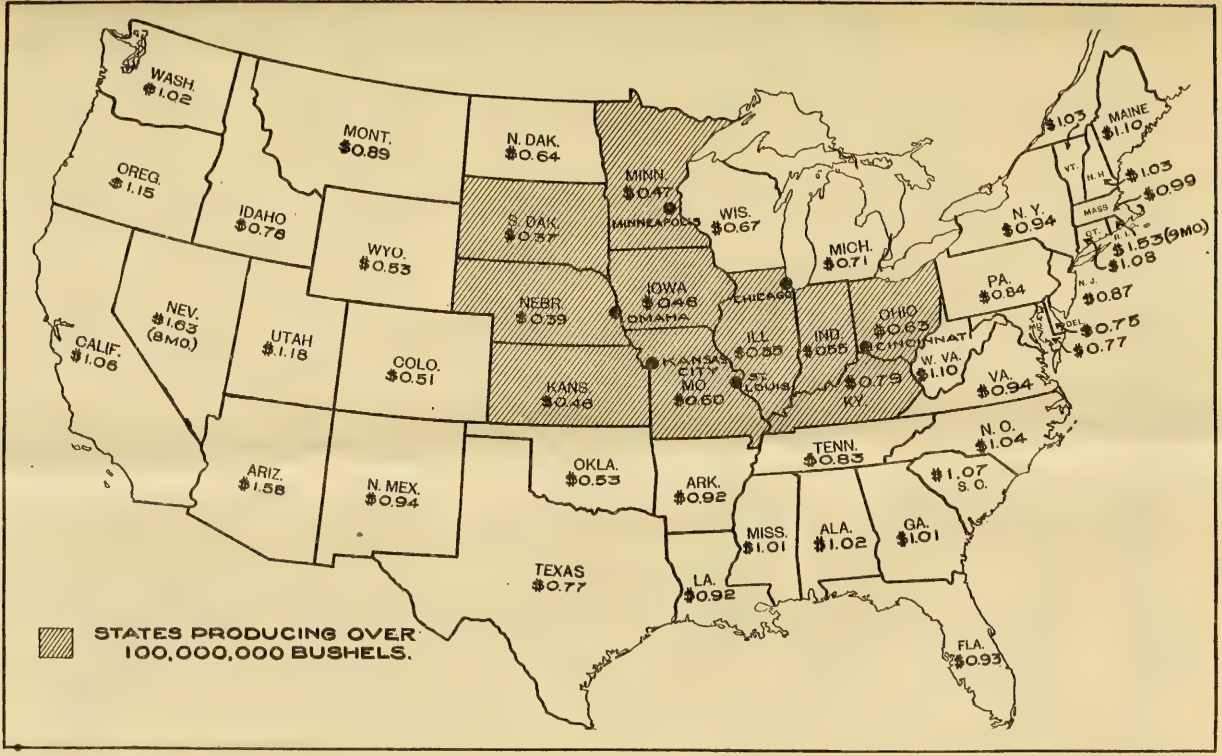

FIG. 19.—Corn: Yearly average State farm price per bushel from November 1, 1920, to October 31, 1921. The "Corn belt" is shown by the shaded portion. The average price per bushel for the United States was $0.637. The low prices center in South Dakota and Nebraska. The prices, influenced by distance and demand, increase in all directions from this center.

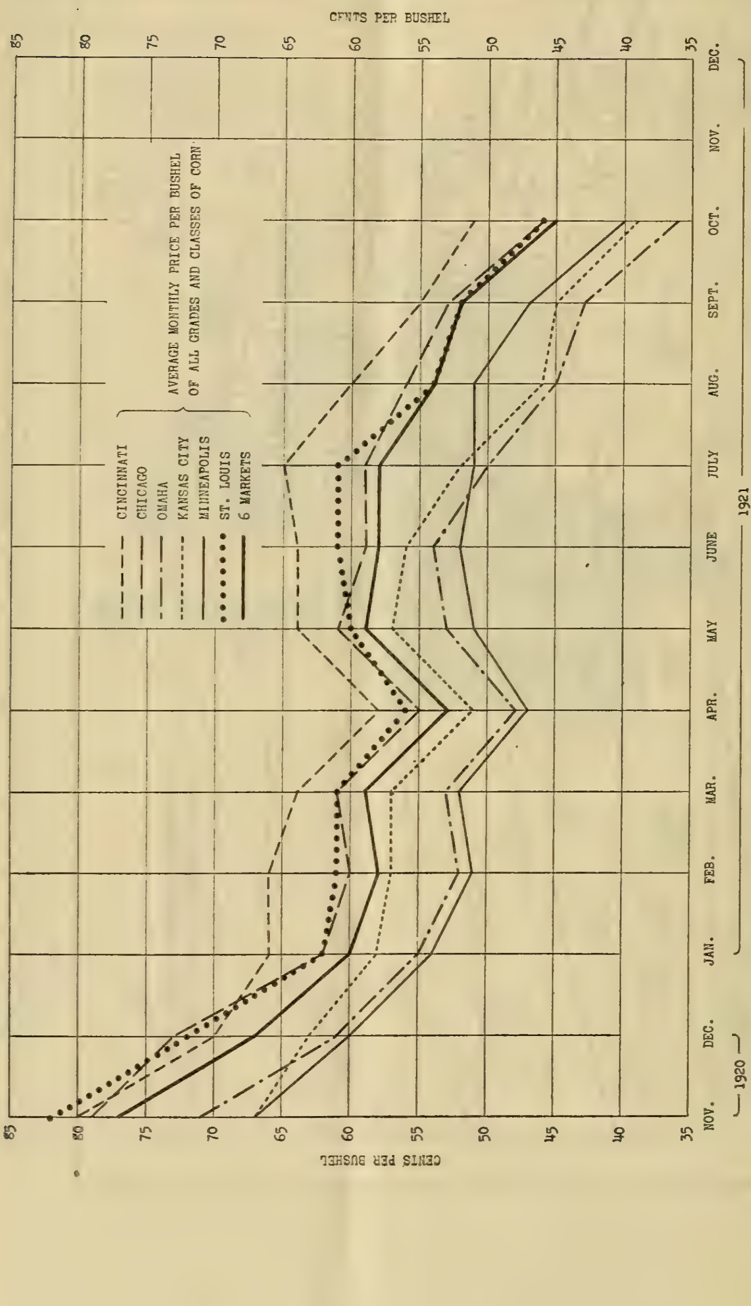

FIG. 20.—Corn: Monthly weighted average price per bushel of all classes and grades at each of six markets and the weighted average price for the combined sales of the six markets during the crop movement year 1920-21. The bulk of sales was made at Chicago which makes that market the controlling factor of the graph.

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21.

CHICAGO AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Chicago.		Farm market price: Illinois, Michigan, Wisconsin, and Iowa (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Chicago.		Farm market price: Illinois, Michigan, Wisconsin, and Iowa (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	August.	3,908	72.1	......	....	......	Aug. 1 to Aug. 31	3,908	72.1	......	......	......
Mixed		20	70.6	......	....	......		20	70.6	......	......	......
Total		3,928	72.0	65.2	22.5	6.8		3,928	72.0	65.2	22.5	6.8
White	September.	3,264	62.3	......	....	......	Aug. 1 to Sept. 30	7,172	67.6	......	......	......
Mixed		17	61.4	......	....	......		37	66.3	......	......	......
Total		3,281	62.2	56.8	11.0	5.4		7,209	67.6	62.6	33.5	5.0
White	October	2,513	54.1	......	....	......	Aug. 1 to Oct. 31	9,685	64.1	......	......	......
Mixed		8	52.5	......	....	......		45	63.9	......	......	......
Total		2,521	54.0	48.6	6.9	5.4		9,730	64.1	60.3	40.4	3.8
White	November.	1,642	50.8	......	....	......	Aug. 1 to Nov. 30	11,327	62.1	......	......	......
Mixed		6	48.9	......	....	......		51	62.1	......	......	......
Total		1,648	50.7	44.5	3.9	6.2		11,378	62.1	58.9	44.3	3.2
White	December.	1,669	48.2	......	....	......	Aug. 1 to Dec. 31	12,996	60.3	......	......	......
Mixed		4	47.4	......	....	......		55	61.0	......	......	......
Total		1,673	48.1	41.1	5.6	7.0		13,051	60.3	56.9	49.9	3.4
	1921.											
White	January	1,974	42.5	......	....	......	Aug. 1 to Jan. 31	14,970	58.0	......	......	......
Mixed		7	44.0	......	....	......		62	59.1	......	......	......
Total		1,981	42.5	38.7	7.6	3.8		15,032	58.0	54.5	57.5	3.5
White	February.	1,281	42.8	......	....	......	Aug. 1 to Feb. 28	16,251	56.8	......	......	......
Mixed		2	39.0	......	....	......		64	58.4	......	......	......
Total		1,283	42.7	37.0	6.4	5.7		16,315	56.8	52.8	63.9	4.0
White	March..	1,900	42.7	......	....	......	Aug. 1 to Mar. 31	18,151	55.3	......	......	......
Mixed		9	42.0	......	....	......		73	56.4	......	......	......
Total		1,909	42.6	35.8	6.2	6.8		18,224	55.3	51.3	70.1	4.0
White	April..	1,472	33.9	......	....	......	Aug. 1 to Apr. 30	19,623	53.7	......	......	......
Mixed		6	34.1	......	....	......		79	54.7	......	......	......
Total		1,478	33.9	31.6	5.8	2.3		19,702	53.7	49.8	75.9	3.9
White	May....	1,711	38.8	......	....	......	Aug. 1 to May 31	21,334	52.5	......	......	......
Mixed		14	36.7	......	....	......		93	52.0	......	......	......
Total		1,725	38.7	32.8	9.1	5.9		21,427	52.5	48.0	85.0	4.5
White	June...	2,428	37.6	......	....	......	Aug. 1 to June 30	23,762	50.9	......	......	......
Mixed		22	34.2	......	....	......		115	48.6	......	......	......
Total		2,450	37.5	31.8	9.1	5.7		23,877	50.9	46.4	94.1	4.5
White	July....	2,929	34.9	......	....	......	Aug. 1 to July 31	26,691	49.2	......	......	......
Mixed		32	30.9	......	....	......		147	44.7	......	......	......
Total		2,961	34.8	28.5	5.9	6.3		26,838	49.1	45.4	100.0	3.7

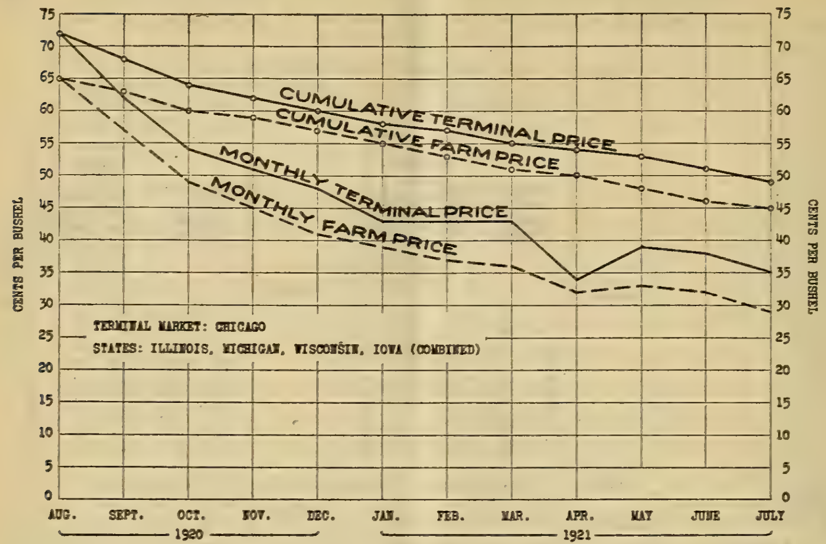

FIG. 21.—Oats: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

MINNEAPOLIS AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Minneapolis.		Farm market price: Minnesota, North Dakota, and South Dakota (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Minneapolis.		Farm market price: Minnesota, North Dakota, and South Dakota (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White....	August....	1,004	66.0	64.5	16.0	1.5	Aug. 1 to 31...	1,004	66.0	64.5	16.0	1.5
White....	September	1,484	57.9	51.2	17.0	6.7	Aug. 1 to Sept. 30.	2,488	61.1	57.7	33.0	3.4
White....	October...	1,163	50.9	43.6	14.1	7.3	Aug. 1 to Oct. 31.	3,651	57.8	53.4	47.1	4.4
White....	November	819	46.8	37.9	7.7	8.9	Aug. 1 to Nov. 30.	4,470	55.8	51.2	54.8	4.6
White....	December.	611	43.7	34.6	7.2	9.1	Aug. 1 to Dec. 31.	5,081	54.3	49.3	62.0	5.0
	1921.											
White....	January...	728	41.0	32.4	7.0	8.6	Aug. 1 to Jan. 31.	5,809	52.7	47.6	69.0	5.1
White....	February.	369	38.8	31.5	6.7	7.3	Aug. 1 to Feb. 28.	6,178	51.8	46.2	75.7	5.6
White....	March.....	488	38.7	30.1	5.7	8.6	Aug. 1 to Mar. 31.	6,666	50.8	45.0	81.4	5.8
White....	April......	146	32.4	27.0	3.0	5.4	Aug. 1 to Apr. 30.	6,812	50.4	44.4	84.4	6.0
White....	May.......	201	34.8	27.1	5.2	7.7	Aug. 1 to May 31.	7,013	50.0	43.4	89.6	6.6
White....	June......	577	34.4	27.6	6.9	6.8	Aug. 1 to June 30.	7,590	48.8	42.3	96.5	6.5
White....	July.......	454	33.8	26.0	3.5	7.8	Aug. 1 to July 31.	8,044	48.0	41.7	100.0	6.3

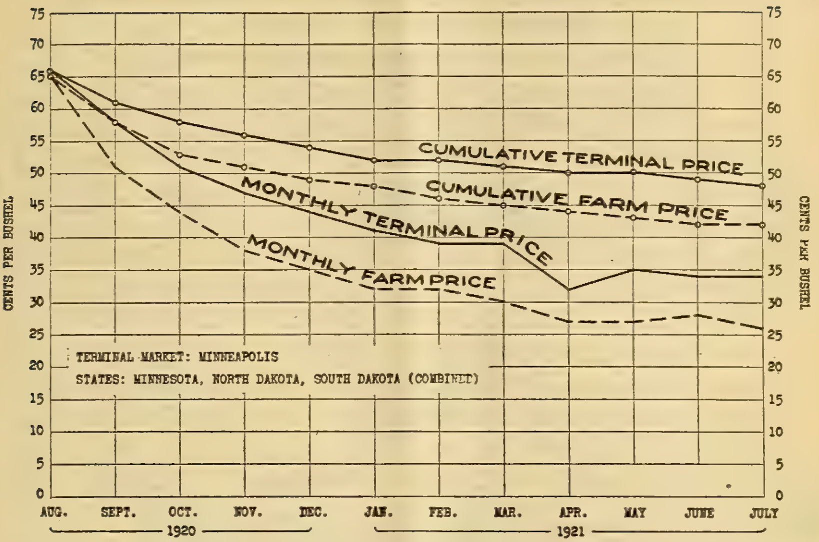

FIG. 22.—Oats: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21— Continued.

ST. LOUIS AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: St. Louis.		Farm market price: Illinois, Iowa, and Missouri (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: St. Louis.		Farm market price: Illinois, Iowa, and Missouri (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
White	August	832	73.0	......	....	......	Aug. 1 to Aug. 31	832	73.0	......	.....	......
Mixed		70	72.7	......	....	......		70	72.7	......	.....	......
Red		54	62.9	......	....	......		54	62.9	......	.....	......
Total		956	72.4	64.6	24.4	7.8		956	72.4	64.6	24.4	7.8
White	September	774	63.2	......	....	......	Aug. 1 to Sept. 30	1,606	68.2	......	.....	......
Mixed		42	63.5	......	....	......		112	69.2	......	.....	......
Red		58	66.7	......	....	......		112	64.8	......	.....	......
Total		874	63.4	56.0	10.1	7.4		1,830	68.1	62.1	34.5	6.0
White	October	654	55.1	......	....	......	Aug. 1 to Oct. 31	2,260	64.4	......	.....	......
Mixed		43	55.9	......	....	......		155	65.5	......	.....	......
Red		24	55.8	......	....	......		136	63.2	......	.....	......
Total		721	55.1	47.5	6.0	7.6		2,551	64.4	59.8	40.5	4.6

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

ST. LOUIS AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table. Terminal market price: St. Louis. Cars involved.	Monthly table. Terminal market price: St. Louis. Weighted average per bushel.	Monthly table. Farm market price: Illinois, Iowa, and Missouri (combined). Weighted average per bushel.	Monthly table. Farm market price: Illinois, Iowa, and Missouri (combined). Per cent of total sales.	Monthly table. Difference between average terminal and average farm price.	Period.	Cumulative table. Terminal market price: St. Louis. Cars involved.	Cumulative table. Terminal market price: St. Louis. Weighted average per bushel.	Cumulative table. Farm market price: Illinois, Iowa, and Missouri (combined). Weighted average per bushel.	Cumulative table. Farm market price: Illinois, Iowa, and Missouri (combined). Per cent of total sales.	Cumulative table. Difference between average terminal and average farm price.
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	November.	456	51.9				Aug. 1 to Nov. 30	2,716	62.3			
Mixed		45	53.0					200	62.7			
Red		29	51.3					165	61.1			
Total		530	51.9	42.7	4.5	9.2		3,081	62.3	58.5	45.0	3.8
White	December.	415	50.0				Aug. 1 to Dec. 31	3,131	60.7			
Mixed		31	49.9					231	60.9			
Red		16	47.1					181	59.9			
Total		462	49.8	39.7	5.4	10.1		3,543	60.6	56.4	50.4	4.2
	1921.											
White	January.	630	45.3				Aug. 1 to Jan. 31	3,761	58.1			
Mixed		112	50.8					343	57.6			
Red		62	47.4					243	56.7			
Total		804	46.2	37.8	7.6	8.4		4,347	58.0	53.9	58.0	4.1
White	February.	307	44.0				Aug. 1 to Feb. 28	4,068	57.0			
Mixed		87	45.0					430	55.0			
Red		47	48.0					290	55.2			
Total		441	44.6	36.2	6.1	8.4		4,788	56.7	52.2	64.1	4.5
White	March	542	43.0				Aug. 1 to Mar. 31	4,610	55.3			
Mixed		68	43.0					498	53.4			
Red		32	45.0					322	54.2			
Total		642	43.0	35.3	6.1	7.7		5,430	55.1	50.7	70.2	4.4
White	April	338	38.4				Aug. 1 to Apr. 30	4,948	54.2			
Mixed		56	36.3					554	51.6			
Red		6	37.3					328	53.9			
Total		400	38.0	33.0	4.5	5.0		5,830	53.9	49.6	74.7	4.3
White	May	503	39.9				Aug. 1 to May 31	5,451	52.8			
Mixed		63	39.1					617	50.4			
Red		8	39.1					336	53.5			
Total		574	39.8	32.3	9.3	7.5		6,404	52.7	47.7	84.0	5.0
White	June	493	38.7				Aug. 1 to June 30	5,944	51.7			
Mixed		17	39.4					634	50.1			
Red		23	37.6					359	52.5			
Total		533	38.6	31.1	8.8	7.5		6,937	51.6	46.1	92.8	5.5
White	July	625	35.9				Aug. 1 to July 31	6,569	50.2			
Mixed		41	34.9					675	49.1			
Red		74	36.3					433	49.7			
Total		740	35.8	28.8	7.2	7.0		7,677	50.1	44.8	100.0	5.3

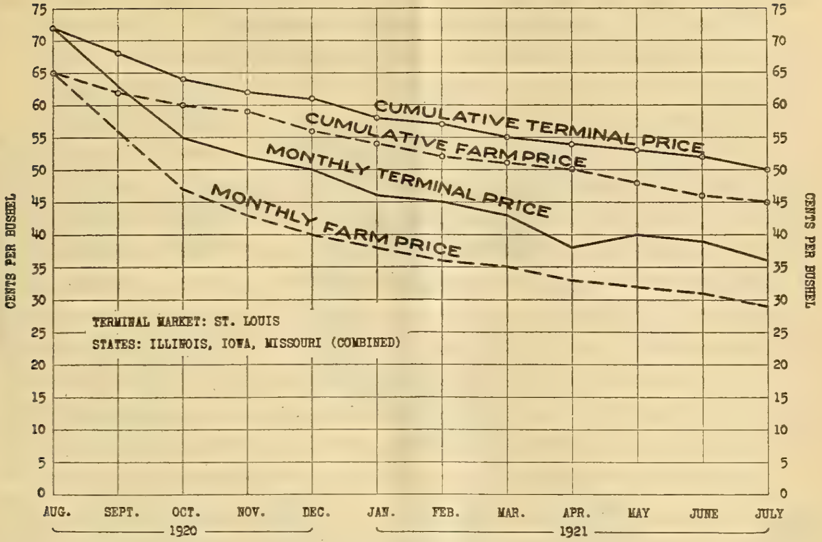

FIG. 23.—Oats: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

OMAHA AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Omaha.		Farm market price: South Dakota, Nebraska, and Iowa (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Omaha.		Farm market price: South Dakota, Nebraska, and Iowa (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	August.	359	68.6				Aug. 1 to Aug. 31	359	68.6			
Mixed		16	67.5					16	67.5			
Total		375	68.5	62.6	23.5	5.9		375	68.5	62.6	23.5	5.9
White	September.	356	59.5				Aug. 1 to Sept. 30	715	64.0			
Mixed		4	59.2					20	65.8			
Total		360	59.5	53.0	12.5	6.5		735	64.1	59.3	36.0	4.8
White	October	468	51.8				Aug. 1 to Oct. 31	1,183	59.2			
Mixed		10	50.7					30	60.7			
Total		478	51.7	44.4	9.0	7.3		1,213	59.2	56.3	45.0	2.9
White	November.	57	46.8				Aug. 1 to Nov. 30	1,240	58.6			
Mixed		3	45.6					33	59.4			
Total		60	46.7	38.5	3.9	8.2		1,273	58.6	54.9	48.9	3.7

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

OMAHA AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Terminal market price: Omaha. Cars involved.	Terminal market price: Omaha. Weighted average per bushel.	Farm market price: South Dakota, Nebraska and Iowa (combined). Weighted average per bushel.	Farm market price: South Dakota, Nebraska and Iowa (combined). Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Omaha. Cars involved.	Terminal market price: Omaha. Weighted average per bushel.	Farm market price: South Dakota, Nebraska, and Iowa (combined). Weighted average per bushel.	Farm market price: South Dakota, Nebraska, and Iowa (combined). Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	December.	207	45.8				Aug. 1 to Dec. 31	1,447	56.8			
Mixed		7	45.6					40	56.9			
Total		214	45.7	36.0	6.1	9.7		1,487	56.8	52.8	55.0	4.0
	1921.											
White	January	252	42.1				Aug. 1 to Jan. 31	1,699	54.6			
Mixed		9	40.8					49	54.0			
Total		261	42.0	34.1	7.5	7.9		1,748	54.6	50.5	62.5	4.1
White	February.	128	39.5				Aug. 1 to Feb. 28	1,827	53.7			
Mixed		6	39.0					55	52.3			
Total		134	39.4	32.5	5.7	6.9		1,882	53.5	49.0	68.2	4.5
White	March	188	39.7				Aug. 1 to Mar. 31	2,015	52.2			
Mixed		12	40.8					67	49.8			
Total		200	39.7	31.9	6.1	7.8		2,082	52.2	37.6	74.3	4.6
White	April	87	34.0				Aug. 1 to Apr. 30	2,102	51.5			
Mixed		2	33.5					69	49.3			
Total		89	33.9	28.9	3.2	5.0		2,171	51.4	46.8	77.5	4.6
White	May	171	36.6				Aug. 1 to May 31	2,273	50.4			
Mixed		9	35.9					78	47.8			
Total		180	36.5	28.5	6.4	8.0		2,351	50.3	45.4	83.9	4.9
White	June	151	34.4				Aug. 1 to June 30	2,424	49.4			
Mixed		9	33.9					87	46.3			
Total		160	34.3	28.2	8.2	6.1		2,511	49.2	43.9	92.1	5.3
White	July	206	32.5				Aug. 1 to July 31	2,630	48.0			
Mixed		11	31.9					98	44.7			
Total		217	32.4	25.8	7.9	6.6		2,728	47.9	39.9	100.0	8.0

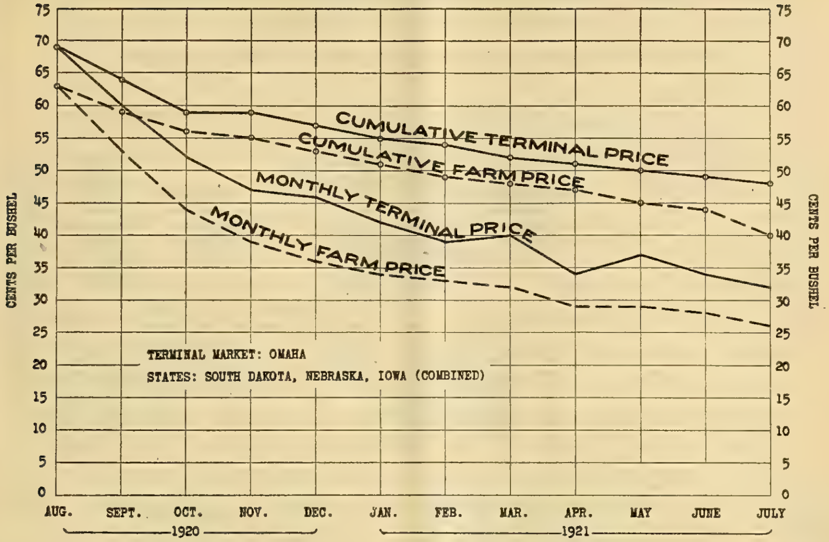

FIG. 24.—Oats: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

KANSAS CITY AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: Kansas City. Cars involved.	Terminal market price: Kansas City. Weighted average per bushel.	Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Kansas City. Cars involved.	Terminal market price: Kansas City. Weighted average per bushel.	Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
White	August	113	71.6				Aug. 1 to Aug. 31	113	71.6			
Mixed		10	68.6					10	68.6			
Red		125	69.3					125	69.2			
Total		248	70.3	63.2	23.1	7.1		248	70.3	63.2	23.1	7.1
White	September.	194	62.7				Aug. 1 to Sept. 30	307	65.3			
Mixed		6	64.0					16	66.8			
Red		87	63.9					212	67.0			
Total		287	63.1	55.9	12.3	7.2		535	66.0	60.6	35.4	5.4
White	October	208	54.7				Aug. 1 to Oct. 31	515	61.0			
Mixed		8	53.7					24	62.4			
Red		53	55.3					265	64.6			
Total		269	54.7	46.9	8.2	7.8		804	62.2	58.0	43.6	4.2

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

KANSAS CITY AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Monthly: Terminal market price: Kansas City. Cars involved.	Monthly: Terminal market price: Kansas City. Weighted average per bushel.	Monthly: Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Weighted average per bushel.	Monthly: Farm market price: Per cent of total sales.	Monthly: Difference between average terminal and average farm price.	Cumulative table. Period.	Cumulative: Terminal market price: Kansas City. Cars involved.	Cumulative: Terminal market price: Kansas City. Weighted average per bushel.	Cumulative: Farm market price: Iowa, Nebraska, Missouri, and Kansas (combined). Weighted average per bushel.	Cumulative: Farm market price: Per cent of total sales.	Cumulative: Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	November.	133	51.1				Aug. 1 to Nov. 30	648	59.0			
Mixed		15	47.9					39	56.8			
Red		51	49.6					316	62.4			
Total		199	50.4	40.7	3.8	9.7		1,003	59.9	56.6	47.4	3.3
White	December.	70	48.6				Aug. 1 to Dec. 31	718	57.9			
Mixed		4	46.5					43	55.9			
Red		30	45.3					346	60.9			
Total		104	47.5	37.6	5.7	9.9		1,107	58.8	54.6	53.1	4.2
	1921											
White	January.	147	46.0				Aug. 1 to Jan. 31	865	55.9			
Mixed		5	43.4					48	54.6			
Red		24	45.7					370	59.9			
Total		176	45.8	35.2	7.0	10.6		1,283	57.2	52.3	60.1	4.9
White	February.	106	42.9				Aug. 1 to Feb. 28	971	54.7			
Mixed		10	41.8					58	52.4			
Red		26	42.7					396	58.8			
Total		142	42.7	34.3	5.8	8.4		1,425	55.8	50.8	65.9	5.0
White	March.	121	43.0				Aug. 1 to Mar. 31	1,092	53.4			
Mixed		6	41.7					64	51.4			
Red		34	40.2					430	57.9			
Total		161	42.3	34.0	6.0	8.3		1,586	54.6	49.4	71.9	5.2
White	April.	45	37.3				Aug. 1 to Apr. 30	1,137	52.8			
Mixed		3	35.7					67	50.8			
Red		7	35.7					437	57.6			
Total		55	37.0	30.3	3.3	6.7		1,641	54.0	48.5	75.2	5.5
White	May.	69	40.2				Aug. 1 to May 31	1,206	52.1			
Mixed		6	39.3					73	49.9			
Red		13	38.0					450	57.0			
Total		88	39.8	30.5	6.5	9.3		1,729	53.3	47.1	81.7	6.2
White	June.	141	37.1				Aug. 1 to June 30	1,347	50.5			
Mixed		9	34.9					82	48.2			
Red		29	35.7					479	55.7			
Total		179	36.7	29.2	8.1	7.5		1,908	51.7	45.5	89.8	6.2
White	July.	83	35.0				Aug. 1 to July 31	1,430	49.3			
Mixed		7	33.5					89	47.0			
Red		30	32.2					509	54.3			
Total		120	34.2	29.2	10.2	5.0		2,028	50.5	43.8	100.0	6.7

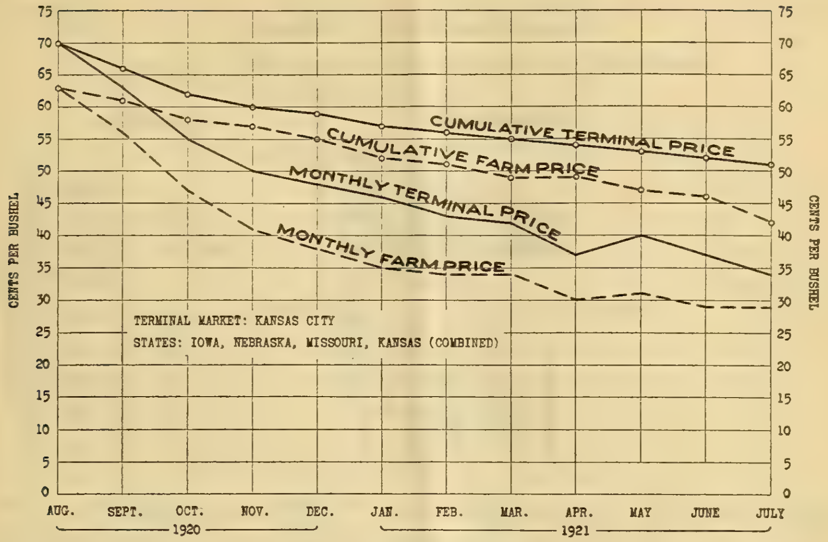

FIG. 25.—Oats: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Oat prices at terminal markets and at farm markets in contributing territory crop movement year 1920–21—Continued.

CINCINNATI AND CONTRIBUTING TERRITORY.

Class.	Monthly table. Month.	Terminal market price: Cincinnati. Cars involved.	Terminal market price: Cincinnati. Weighted average per bushel.	Farm market price: Ohio, Indiana, and Michigan (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Cincinnati. Cars involved.	Terminal market price: Cincinnati. Weighted average per bushel.	Farm market price: Ohio, Indiana, and Michigan (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
White	August	105	73.7	......	....	......	Aug. 1 to Aug. 31	105	73.7	......	.....	......
Mixed		7	70.6	......	....	......		7	70.6	......	.....	......
Total		112	73.5	69.8	24.7	3.7		112	73.5	69.8	24.7	3.7
White	September	129	62.4	......	....	......	Aug. 1 to Sept. 30	234	67.4	......	.....	......
Mixed		1	66.0	......	....	......		8	70.0	......	.....	......
Total		130	62.4	60.4	15.6	2.0		242	67.5	66.2	40.3	1.3
White	October	78	55.5	......	....	......	Aug. 1 to Oct. 31	312	64.1	......	.....	......
Mixed		5	56.0	......	....	......		13	64.6	......	.....	......
Total		83	55.5	53.3	8.1	2.2		325	64.1	64.0	48.4	0.1
White	November	66	51.8	......	....	......	Aug. 1 to Nov. 30	378	61.9	......	.....	......
Mixed		8	52.2	......	....	......		21	59.8	......	.....	......
Total		74	51.8	49.4	4.9	2.4		399	61.8	62.7	53.3	−0.9

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CINCINNATI AND CONTRIBUTING TERRITORY—Continued.

Class.	Month.	Monthly table.					Period.	Cumulative table.				
		Terminal market price: Cincinnati.		Farm market price Ohio, Indiana, and Michigan (combined).		Difference between average terminal and average farm price.		Terminal market price: Cincinnati.		Farm market price: Ohio, Indiana, and Michigan (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	December	68	50.8	......	....	......	Aug. 1 to Dec. 31	446	60.2	......	......	......
Mixed		5	51.4	......	....	......		26	58.2	......	......	......
Total		73	50.8	46.9	5.3	3.9		472	60.1	61.2	58.6	−1.1
	1921.											
White	January	72	52.0	......	....	......	Aug. 1 to Jan. 31	518	59.1	......	......	......
Mixed		10	46.8	......	....	......		36	55.0	......	......	......
Total		82	51.3	43.4	6.0	7.9		554	58.8	59.6	64.6	−0.8
White	February	49	44.9	......	....	......	Aug. 1 to Feb. 28	567	57.8	......	......	......
Mixed		6	40.4	......	....	......		42	52.9	......	......	......
Total		55	44.4	40.4	4.9	4.0		609	57.5	58.2	69.5	−0.7
White	March	64	44.7	......	....	......	Aug. 1 to Mar. 31	631	56.5	......	......	......
Mixed		7	44.3	......	....	......		49	51.7	......	......	......
Total		71	44.6	39.4	5.2	5.2		680	56.1	56.9	74.7	−0.8
White	April	62	39.8	......	....	......	Aug. 1 to Apr. 30	693	55.0	......	......	......
Mixed		10	38.9	......	....	......		59	49.5	......	......	......
Total		72	39.6	36.6	6.7	3.0		752	54.6	55.2	81.4	−0.6
White	May	63	41.1	......	....	......	Aug. 1 to May 31	756	53.8	......	......	......
Mixed		4	40.5	......	....	......		63	48.9	......	......	......
Total		67	41.0	35.5	7.1	5.5		819	53.5	53.7	88.5	−0.2
White	June	64	39.2	......	....	......	Aug. 1 to June 30	820	52.7	......	......	......
Mixed		7	37.6	......	....	......		70	47.8	......	......	......
Total		71	39.0	35.1	8.1	3.9		890	52.3	52.1	96.6	0.2
White	July	138	36.8	......	....	......	Aug. 1 to July 31	958	50.4	......	......	......
Mixed		5	35.7	......	....	......		75	47.0	......	......	......
Total		143	36.7	33.6	3.4	3.1		1,033	50.1	51.5	100.0	−1.4

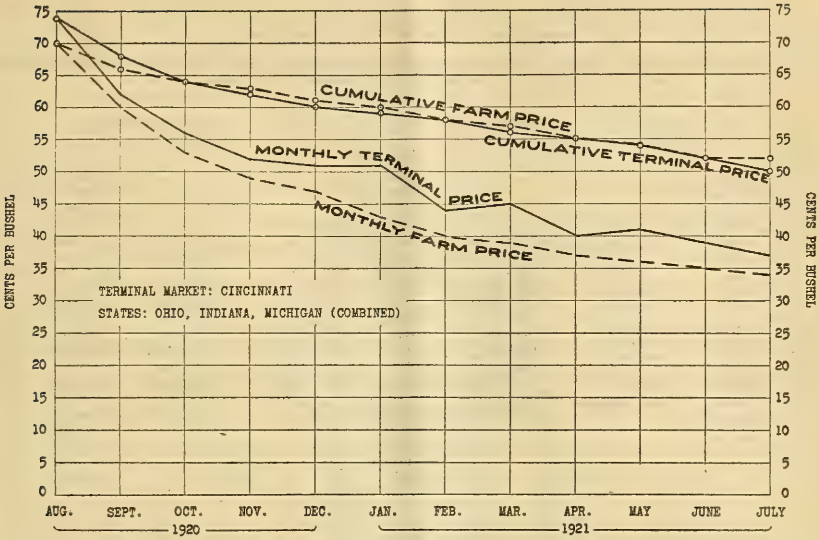

FIG. 26.—Oats: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO, MINNEAPOLIS, ST. LOUIS, OMAHA, KANSAS CITY, AND CINCINNATI (COMBINED), AND CONTRIBUTING TERRITORY.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Chicago, Minneapolis, St. Louis, Omaha, Kansas City, and Cincinnati (combined).		Farm market price: Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Chicago, Minneapolis, St. Louis, Omaha, Kansas City, and Cincinnati (combined).		Farm market price: Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1920.		Cents.	Cents.		Cents.	1920.		Cents.	Cents.		Cents.
White	August	6,321	71.0	......	......	......	Aug. 1 to Aug. 31	6,321	71.0	......	......	......
Mixed		123	71.2	......	......	......		123	71.2	......	......	......
Red		179	67.3	......	......	......		179	67.3	......	......	......
Total		6,623	70.9	65.7	21.9	5.2		6,623	70.9	65.7	21.9	5.2
White	September.	6,201	61.2	......	......	......	Aug. 1 to Sept. 30	12,522	66.1	......	......	......
Mixed		70	62.8	......	......	......		193	68.1	......	......	......
Red		145	65.0	......	......	......		324	66.3	......	......	......
Total		6,416	61.3	56.3	12.6	5.0		13,039	66.2	62.2	34.5	4.0

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO, MINNEAPOLIS, ST. LOUIS, OMAHA, KANSAS CITY, AND CINCINNATI (COMBINED), AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table. Month.	Terminal market price: Chicago, Minneapolis, St. Louis, Omaha, Kansas City, and Cincinnati (combined). Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.	Cumulative table. Period.	Terminal market price: Chicago, Minneapolis, St. Louis, Omaha, Kansas City, and Cincinnati (combined). Cars involved.	Terminal market price: Weighted average per bushel.	Farm market price: Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas (combined). Weighted average per bushel.	Farm market price: Per cent of total sales.	Difference between average terminal and average farm price.
	1920.		*Cents.*	*Cents.*		*Cents.*	1920–21.		*Cents.*	*Cents.*		*Cents.*
White	October.	5,084	53.3				Aug. 1 to Oct. 31	17,606	62.4			
Mixed		119	54.9					312	63.1			
Red		32	55.2					356	65.3			
Total		5,235	53.3	47.4	8.0	5.9		18,274	62.5	59.4	42.5	3.1
White	November.	3,173	49.8				Aug. 1 to Nov. 30	20,779	60.5			
Mixed		77	51.3					389	60.7			
Red		80	50.2					436	62.5			
Total		3,330	49.9	43.0	4.7	6.9		21,604	60.5	57.8	47.2	2.7
White	December.	3,040	47.4				Aug. 1 to Dec. 31	23,819	58.8			
Mixed		51	49.8					440	59.5			
Red		46	45.9					482	60.9			
Total		3,137	47.4	40.0	5.8	7.4		24,741	58.9	55.9	53.0	3.0
	1921.											
White	January.	3,803	42.9				Aug. 1 to Jan. 31	27,622	56.6			
Mixed		143	49.2					583	56.9			
Red		86	46.9					568	58.8			
Total		4,032	43.2	37.8	7.1	5.4		28,773	56.7	53.7	60.1	3.0
White	February	2,240	42.1				Aug. 1 to Feb. 28	29,862	55.5			
Mixed		111	44.0					694	54.9			
Red		73	46.1					641	57.3			
Total		2,424	42.3	36.2	6.2	6.1		31,197	55.5	52.1	66.3	3.4
White	March.	3,303	42.0				Aug. 1 to Mar. 31	33,165	54.2			
Mixed		102	42.6					796	53.3			
Red		66	42.5					707	55.9			
Total		3,471	42.0	35.4	6.0	6.6		34,668	54.2	50.7	72.3	3.5
White	April.	2,150	34.7				Aug. 1 to Apr. 30	35,315	53.0			
Mixed		77	36.3					873	51.8			
Red		13	36.4					720	55.6			
Total		2,240	34.8	33.5	4.8	1.3		36,908	53.0	49.6	77.1	3.4
White	May.	2,718	38.6				Aug. 1 to May 31	38,033	52.0			
Mixed		96	38.5					969	50.5			
Red		21	38.4					741	55.1			
Total		2,835	38.6	32.1	7.9	6.5		39,743	52.0	48.0	85.0	4.0

Oat prices at terminal markets and at farm markets in contributing territory, crop movement year 1920–21—Continued.

CHICAGO, MINNEAPOLIS, ST. LOUIS, OMAHA, KANSAS CITY, AND CINCINNATI (COMBINED), AND CONTRIBUTING TERRITORY—Continued.

Class.	Monthly table.						Cumulative table.					
	Month.	Terminal market price: Chicago, Minneapolis, St. Louis, Omaha, Kansas City, and Cincinnati (combined).		Farm market price: Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas (combined).		Difference between average terminal and average farm price.	Period.	Terminal market price: Chicago, Minneapolis, St. Louis, Omaha, Kansas City, and Cincinnati (combined).		Farm market price: Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas (combined).		Difference between average terminal and average farm price.
		Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.			Cars involved.	Weighted average per bushel.	Weighted average per bushel.	Per cent of total sales.	
	1921.		Cents.	Cents.		Cents.	1920–21.		Cents.	Cents.		Cents.
White	June	3,854	37.1	......	....	......	Aug. 1 to June 30	41,887	50.6	......	.....	......
Mixed		64	36.0	......	....	......		1,033	49.6	......	.....	......
Red		52	36.5	......	....	......		793	53.9	......	.....	......
		3,970	37.1	29.7	8.4	7.4		43,713	50.6	46.4	93.4	4.2
White	July	4,435	34.8	......	....	......	Aug. 1 to July 31	46,322	49.1	......	.....	......
Mixed		96	33.1	......	....	......		1,129	48.2	......	.....	......
Red		104	35.1	......	....	......		897	51.7	......	.....	......
Total		46,35	34.8	29.4	6.6	5.4		48,348	49.0	45.3	100.0	3.7

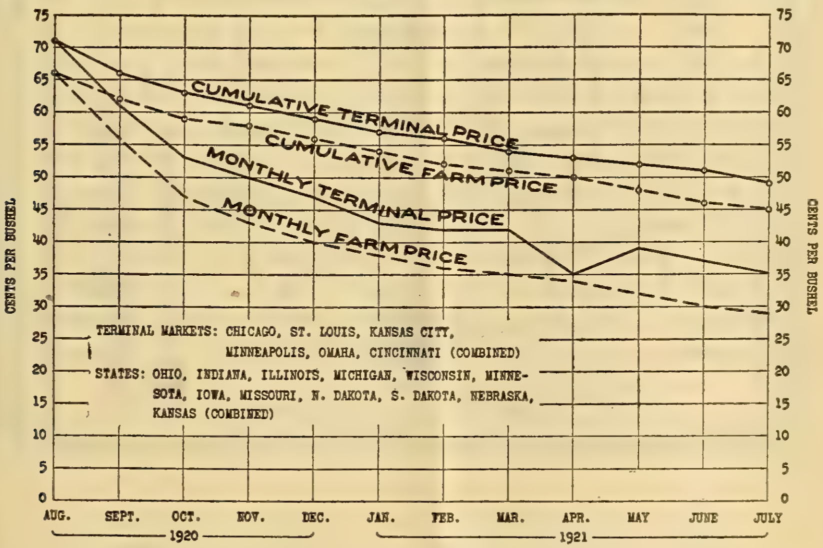

FIG. 27.—Oats: Monthly and cumulative weighted average farm and terminal prices per bushel for crop movement year 1920–21.

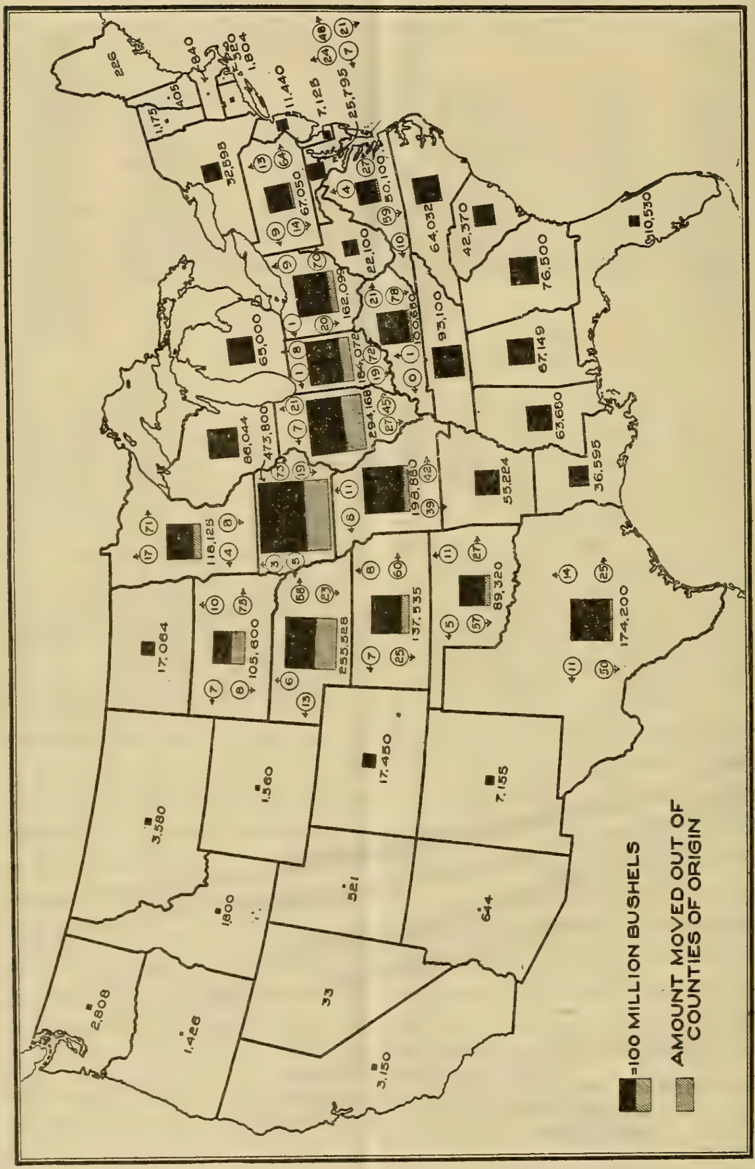

FIG. 28.—Oats: Production and movement by States, 1920 crop. Production figures represent thousands of bushels, i. e., 000 omitted. Black portions of squares represent home consumption and the shaded portions the amount moved out of county where grown. Figures in circles represent the percentage of the crop moved out of the county where grown in the direction indicated by arrows. Movement data not available for some States.

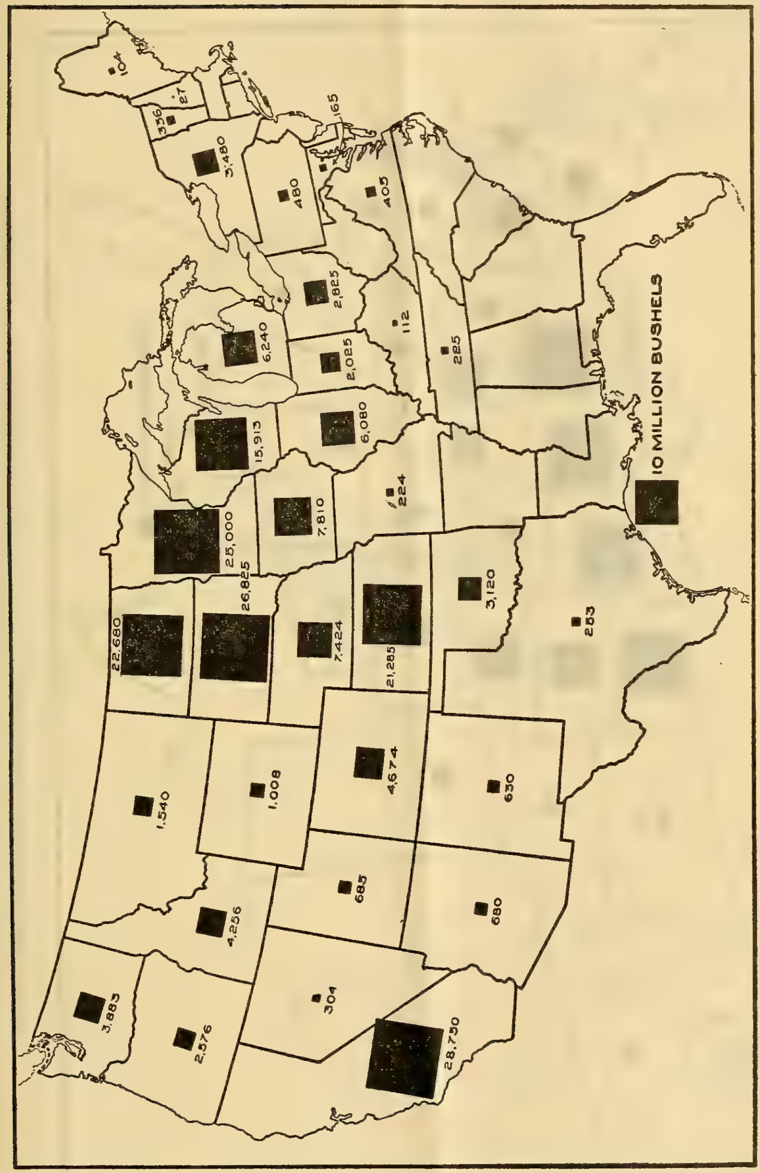

FIG. 29.—Barley: Production by States, 1920 crop. Figures represent thousands of bushels, i. e., 000 omitted. California, the leading State in production, quotes prices for barley as a feed grain.

FIG. 30.—Rye: Production by States, 1920 crop. Figures represent thousands of bushels, i. e., 000 omitted.

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UNITED STATES DEPARTMENT OF AGRICULTURE

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INSPECTION OF FRUIT AND VEGETABLE CANNERIES.

Compiled by F. B. LINTON, *Assistant to the Chief, Bureau of Chemistry,* from reports furnished by a committee of food inspectors of the Bureau of Chemistry, consisting of J. R. GARNER, G. H. ADAMS, and A. S. DAGGETT.[1]

CONTENTS.

INTRODUCTION.

The food inspector has many functions which vary with the terms of the law under which he operates and with the form of the organization which directs his activities. His two primary functions,

[1] In the compilation of this bulletin free use has been made of material from unpublished reports of food inspectors of the Bureau of Chemistry, U. S. Department of Agriculture, who work under the terms of the Federal Food and Drugs Act, especially that collected by the committee appointed by the chief of the bureau for the purpose, and from the following U. S. Government publications: Department of Agriculture Bulletins 569, "The Sanitary Control of Tomato-Canning Factories," by B. J. Howard and C. H. Stephenson, and 196, "Methods Followed in the Commercial Canning of Foods," by A. W. Bitting; Bureau of Chemistry Bulletin 151, "The Canning of Foods"; Department of Commerce, Miscellaneous Series, Bulletin 54, "Canned Foods"; and circulars issued by the War Department giving instructions and specifications pertaining to the inspection of canned fruits and vegetables.

Acknowledgment is made to H. H. Wagner, C. S. Brinton, A. Stengel, and W. R. M. Wharton for helpful criticism and suggestions in the revision of the manuscript.

essential under any form of effective food-law control, however, are to observe and report on the operation of food factories.

This publication considers the two primary functions as applied to the inspection of fruit and vegetable canneries. It does not take up the many other duties which may devolve upon the food inspector, nor does it attempt to go into his legal powers or authority, as these depend upon the particular law under which he operates. It is intended to furnish information on the inspection of fruit and vegetable canneries which will be helpful in operating under any food-control law. The point of view from which the material is treated is confined to the making of cannery inspections for the purpose of preparing a report that will serve as a basis for administrative action in the enforcement of a food-control law. In both the selection and treatment of material this publication differs from one intended to serve as a guide for increasing the efficiency of the cannery processes or to indicate how an inspection in purchasing canned food should be made.

ELEMENTS OF CANNERY INSPECTION.

RELATIONS WITH THE PROPRIETOR.

Establishing right relations with the proprietor is the first important step in making an inspection of a cannery. Approach the man in charge in a courteous, dignified manner. An arrogant attitude, based upon powers conferred by legal authority, excites antagonism and is always inexcusable. The food inspector is the authorized representative of a Federal, State, or city government engaged in the performance of a duty imposed by law, the right performance of which will be of benefit to the proprietor and to the public, as well as a credit to himself and to the service which he represents.

The inspector will find that it increases his efficiency to be uniformly courteous and dignified, regardless of the attitude of the proprietor. Even when the proprietor shows reluctance to having an inspection made, or places obstacles in the way of the inspector in securing the information he needs, the inspector's object can best be attained through handling the situation in a calm and courteous manner. In assuming that people are honest and willing to do the right thing and in approaching them on that basis, the inspector will be right most of the time. Furthermore, this assumption will tend to inspire men with the desire to do the right thing.

Little difficulty will be experienced in obtaining exact information when the cooperation of the proprietor is freely given. In examining complicated processes, the member of the factory force who is accompanying the inspector may overlook some details with-

out any intention to be misleading. Because of his familiarity with the complex machinery, he may omit to mention the use for which certain units are employed, or it may be difficult for him to describe a process in the noise and confusion of the factory. Do not assume that he is deliberately withholding information unless subsequent events prove that such is the case. In order that no part of his explanations will be overlooked, misconstrued, or misunderstood, a safe rule is to take enough time to understand each piece of machinery and its purpose, making notes and illustrations when desirable.

EXAMINATION OF RAW MATERIALS.

Examine critically all raw fruits and vegetables on hand. In studying the raw materials, ascertain where they are produced. Do they come from farms owned or leased by the canner or are they purchased from independent growers? Learn how they are transported to the cannery, whether by wagon, truck, or train. It is important to find out the time that elapses from the picking or harvesting until the fruits and vegetables reach the cannery and the time they are held at the cannery before processing.

Observe carefully whether the raw fruits and vegetables are green, partly mature, ripe, or overripe, and to what extent, if any, they are decayed, bruised by rough handling, defective because of insect stings or fungus injury, or frost bitten. Note the containers in which they are delivered to the cannery. Freedom from bruises and crushing is attained only by the use of suitable containers. Berries should be in small boxes as for the market, and corn, peas, and beans should be handled in such a way that they will not heat. Ask about the weather during the growing and harvesting season and study the general climatic conditions of the section. The climate and its variations have a direct bearing on the quality of the finished product.

Ascertain all the varieties of each product handled regularly, so that later in the inspection statements about the varieties appearing in the labeling may be checked. As a rule, the variety is mentioned only in the labels of fruits and vegetables having one or more varieties for which there is a greater demand than for the others. When a particular variety is specified in the label, it is important that the inspector should know whether or not that variety is actually put into the can.

The importance of starting with fresh, sound, clean, properly matured fruit or vegetables can not be too strongly emphasized. No matter how careful or efficient the canning process may be, it can never improve the quality of unsound fruit or vegetables.

SURROUNDINGS OF THE CANNERY.

Make a survey of the surroundings of the cannery, noting every feature that may have a bearing on the health and efficiency of the employees or the wholesomeness and quality of the finished product. Is the cannery surrounded by high buildings that obstruct the light? Are any near-by factories giving off offensive fumes or odors? A fertilizer plant, for instance, in the immediate vicinity of a cannery should be reported.

The draining of the cannery should be as nearly perfect as possible. Every cannery has large quantities of waste products, such as trimmings, cores and peelings, and these, if allowed to accumulate in open containers or in drains near the cannery, become a source of contamination. Observe the locations of stables, pigsties, privies, and the like, which might breed flies, or, because of nearness to the cannery, become a source of contamination to the water supply. Is the factory on a dusty road or street, or are the approaches to it sprinkled or oiled and kept in such a condition that the minimum quantity of dust enters the building?

CANNING PROCESSES.

The efficient inspector gives careful attention to every detail of the canning processes for each product put up in the cannery, as the processes vary with the different fruits and vegetables. Note the number and the make of machines and any peculiarity in their method of operation or the way in which the product is handled from start to finish.

The processes of sorting, grading, washing, and preparing the fruits and vegetables, and filling, exhausting, capping, then processing or sterilizing and cooling the filled cans are common for all fruits and vegetables. These processes should be studied separately, the inspector noting any defects that might in any way affect the quality of the finished product.

SORTING.

The elimination of all rotten, partly rotten, or otherwise defective fruits or vegetables is the chief object in sorting. Efficient sorting can not be done without good light. Where natural light, which is always to be preferred, is not available, sufficient electric or other good artificial light should be provided for the sorting tables. Observe the number of sorters and their skill as evidenced by the effectiveness of their work. Determine the rate of speed with which the products pass the sorters. Are there any turning devices on the tables to enable the sorters to see the product from all sides? All arrangements that contribute to the comfort of the sorters make for greater efficiency.

Grading for size is usually done by machinery. While important, grading for size, texture, and color is secondary to the elimination of defective products. Examine the fruit or vegetables after they pass the sorters to see whether or not any defective products pass, and if so, what percentage.

WASHING.

Give careful attention to the method of washing and note the make and kind of machines used. There is a tendency on the part of some canners to depend too much upon sterilization, neglecting both sorting and washing. Note the sufficiency and purity of the water supply, which sometimes runs low, resulting in inefficient washing. Is the wash water flowing continuously? If not, how often is it changed? A common arrangement for washing is a tank of water which is agitated so as to cause the fruits or vegetables to move gently through the water toward one end of the tank, from which they are elevated and forced under a strong spray of water as they leave the tank. The effectiveness of the spray depends both upon its force and upon its volume. A good spray is valuable in removing dirt and mold from the surface of the fruits or vegetables. Peas and some other similar products are often washed in a revolving cylinder called a "squirrel cage," but other machines are also used for this purpose. Examine specimens of the fruit and vegetables after they come from the washing process to see if any dirt or mold still clings to them.

PREPARATION.

In the preparation of fruits and vegetables for canning, such operations as peeling and cutting to size, in fact all those that are performed by hand, should be done by workers free from communicable diseases. Apples, pears, and usually peaches are peeled and cut to size; peas are shelled and blanched; corn is husked, silked, and cut from the cob; beans are snipped, strung, and blanched; asparagus is cut into lengths and blanched; sweet potatoes and beets are peeled. Is all the waste discarded or is it utilized for any purpose? All waste should be used or discarded promptly, not allowed to accumulate and ferment.

Blanching is not for the purpose of changing the color, as might be inferred from the name, but it is a parboiling to make the product more suitable for packing in the can. Vegetables are usually blanched for from 1 to 5 minutes. Blanching causes a softening of the tissue and in some cases removes mucous substances from the surfaces.

FILLING.

The method of filling the can depends upon the product. Peaches, pears, apples, and the like are put in the can by hand, but special machines have been adapted for many fruits and vegetables. The

inspector should observe what method is used for washing the cans before the filling process is begun, since dirt and dust may accumulate in cans during transportation and storage. Give careful attention to the machines used for filling, especially their control and regulation. Do they result in a uniform fill? As soon as the fruit and vegetables are put in the can, the sirup or brine is added. Cans should be filled as full of solid food as is practicable, with only such quantity of sirup or brine as is necessary for proper processing. Are any spices or other substances used in addition to the brine or sirup? Note the degree of sirup used, for the different grades, and also the strength of the brine.

As water is one of the cheapest adulterants, the inspector should give careful attention to ascertaining whether or not it is added in a greater amount than is necessary. He should discover also whether the cans are "slack filled," that is, contain too much brine or sirup and too little solid food. Slack fill may be due to deliberate intention of the canner, to imperfect control of the filling operation, or to a lack of knowledge of what is a standard fill. The effect on the consumer is exactly the same in each case.

Observe whether the method of exhausting is by heating the product or by capping in vacuum, and give the names of the machines used. Report whether the cans have open or soldered tops. What method is used in testing the cans for leaks after they have been sealed? State the make of or describe the sealing machines.

PROCESSING.

The inspector should note and describe in his report the whole operation of processing, including the machinery used. When practicable ascertain the pressure and the temperature employed and the time for reaching the maximum in the case of all the products canned. How are these factors controlled? Find out whether the time, temperature, and pressure as stated in any directions that may be issued by the manager are carefully observed by the employees. Since overprocessing may make the fruit in the can soft or otherwise undesirable, some canners occasionally underprocess. As this sometimes fails to kill the microorganisms present, spoilage may follow, attended by the possibility that botulism lurks in the can.

Are the different batch numbers marked? If so, how? Is a record kept of the temperature, time, and pressure of each batch? This may be important later in tracing the cause of any spoilage that occurs. If a spoiled can is identified by a batch number and careful records of that batch have been kept, the cause of the spoilage may be determined and the responsibility for it fixed.

COOLING.

Describe the methods, temperature, and time of cooling the cans. Prompt and adequate cooling is essential in the case of certain products, such as tomatoes, peas, and string beans. Some canners believe that the cloudy liquor occasionally found in canned peas and beans is caused by an excessive fill before the brine is added. As a matter of fact, it usually is due to insufficient cooling of the hot cans in cold water before they are placed in the storehouse. Canned tomatoes, peas, and string beans may be spoiled by "stack burning" unless they are quickly and thoroughly cooled as soon as they are removed from the process kettle.

FINISHED PRODUCTS.

Examine the stock of filled cans, noting the manner in which they have been stored and any evidence of spoilage or defective processing. Look especially for signs of swelling in the cans. So-called "swells" indicate spoilage, for the normal can has straight sides and flat or slightly concave ends. Convex or bulging ends indicate the probability of spoilage. Some cans, called "springers," however, have slightly convex ends caused by overfilling or incomplete exhausting. The ordinary swell is the result of gas formation within the can and usually indicates spoilage. One type of bulging is caused by the presence of hydrogen liberated by the action of the contents on the metal of the can, not by spoilage of the contents of the can. The so-called "flat sours," another form of spoilage, do not make the cans swell. This form can be detected only by the acidity test or by the taste. Look also for signs of rust in the cans; rusty cans may develop leaks.

Report the annual output of each product. Ascertain how long on the average the stock is held in storage before shipment. Is there any stock from packs of previous years on hand? If so, how much and how long has it been held? How is the stock stored? What is its condition? What disposition is made of returned "swells"?

Examine carefully the contents of some of the cans in stock. Test the vacuum of the can. Note the odor immediately upon opening. If the inspector is familiar with the characteristic odor of the sound fruit or vegetable, he will have little difficulty in detecting any spoilage that may have developed in the cans. Note the flavor and the consistency of the product and the clearness or the turbidity of the liquor. Are any pods, leaves, stems, or other foreign or decayed matter present? Attention should be given to the quantity of the contents of the can. Weigh the can filled and sealed, weigh separately the brine or sirup drained from the

can, and then weigh separately the fruit or vegetables after the brine or sirup has been drained off; also weigh the empty cans.

The inspector should know the standard drained weights for the various fruits and vegetables in cans of different sizes. The Bureau of Chemistry has published standards of drained weight for a number of fruits and vegetables, copies of which may be obtained upon application to the bureau. If the department in which the inspector is working does not have standards of its own, the standards adopted by the Bureau of Chemistry will be found useful as a guide.

Both short weight and slack fill may be due to lack of proper control of the filling operation, to carelessness in the control of the filling operation, or to deliberate intention to put in short weight or too much brine or sirup. Spoilage may be due to underprocessing, to defective containers, or to the use of imperfect or unfit materials. If, in examining the finished product, the inspector finds any evidence of short weight, slack fill, or spoilage, he should endeavor to ascertain the cause, if his inspection up to this point has not already indicated it.

GRADES.

The lack of standardization of grades for fruits and vegetables makes it difficult for the inspector to detect any but the more glaring misstatements regarding grades. The grades for fruits and vegetables vary not only in different sections of the country but even with different packers in the same section. Furthermore, one packer's grades not infrequently vary from year to year. This is sometimes due to the variations in the fruits and vegetables caused by differing seasons or other factors in the growing of crops. Until grades have been legally standardized, the food-law official can do little more than prevent flagrant misbranding in this respect. The matter of variations in grade can usually be settled between buyer and seller by price adjustment.

If the fruits and vegetables in the can are good and wholesome, the question of whether they are the highest grade or the standard grade, under existing conditions, makes little difference, so long as they are not misbranded and are sold for a price that is fair for the grade in the can. Injury is done to the consumer when the canner attempts to put out a standard grade for an extra fancy grade, at the price of the extra fancy grade. The question of how much the inspector may really do in the matter of grades depends, of course, upon the terms of the law under which he is operating.

The inspector should know how many grades are being put up by the canner and how each grade is designated on the label. Watch particularly for the tendency to make a lower grade appear on the labels as a higher grade. Grading for size is largely done by ma-

chines, but grading for quality—such as uniform texture and color—is done by hand. The inspector should know how carefully the grading is done, the means for supervising or controlling it, how the grades are designated upon the labels, and to what extent differences in grade are emphasized upon the labels.

In issuing instructions to inspectors of canned foods the Army lefined grades as follows:

Foods may be graded according to size or quality, or both. Grading for size s largely mechanical, whereas grading for quality (uniform texture, color, etc.) is usually by hand. The various grades do not follow fixed standards, out vary according to locality and weather conditions of the season. There is a tendency at present toward uniformity and standardization of grades.

FRUITS.

The higher grades differ mainly in the size of the pieces of fruit and in the strength of the sirup. *Sirup strength* is usually measured by degrees on a hydrometer. The Balling and Brix hydrometers both give directly the percentage of sugar in solution. For example, a 40° sirup consists of 40 pounds of sugar and 60 pounds of water in 100 pounds of sirup. Since the Brix hydrometer is used most frequently in the large fruit-canning sections in the West, densities in this manual will be expressed in Brix degrees unless otherwise stated.

The Baumé hydrometer, which has an arbitrary scale, is sometimes used. The following table shows the relation between the Baumé and Brix readings:

Degrees Brix (per cent of sugar).	Degrees Baumé.
10.0	5.6
20.0	11.1
30.0	16.5
40.0	21.9
50.0	27.2

It should be borne in mind that after the fruit is cooked with the sirup the ensity of the latter on the finished product will not be the same as when dded.

California Fruits.

California fruits present the greatest number of grades, which in general re as follows:

(1) *Special extra.*—Choicest specimens of prime, ripe, large fruit, even in olor and texture, and perfectly peeled, pitted, or prepared. Very heavy sirup (about 50°) is used and the product is almost a preserve. The production of his grade is limited in quantity.

(2) *Extra.*—Large, prime, ripe fruit of uniform size, evenly colored, of fine exture, free from blemish, and packed in heavy sirup (about 40°). Cleaning, peeling, pitting, etc., must be perfect.

(3) *Extra standard.*—Prime, ripe fruit of slightly smaller size and less regular than extra, and packed in about 30° sirup. The quality of the fruit nd its preparation are almost equal to the extra. The quality of this grade is igh in value.

(4) *Standard.*—Fruit smaller in size than extra standard, or orchard run fter removal of culls; not so uniform in ripeness nor so even in color as (3); ay have some blemishes; packed in about 20° sirup.

(5) *Seconds.*—Small, hard, or off-colored fruit and irregular pieces, packed in weak sirup (about 10°).

(6) *Water or pie grade.*—Similar to seconds; may also contain soft or overripe fruit; packed in water.

Other Fruits.

In localities where the fruit crop is not so abundant the number of grades and their requirements may be curtailed. Baltimore fruits have been graded as follows:

(1) *Extra.*—Similar to extra standard as above or better, except that the sirup is weaker (20° and upward).

(2) *Standard.*—Similar to standard as above, except that the sirup is weaker (about 10°).

(3) *Seconds.*—Similar to seconds as above, except that the fruit is packed in water.

(4) *Water or pie.*—Similar to same grade as above.

VEGETABLES.

Grading for size is independent of true grading for quality. This varies according to the nature of the vegetable and will be taken up under the separate items. The smaller sizes are more tender and these grades of size are approximately grades of quality.

Quality.—The condition and quality of the food itself is the main factor in grading vegetables. The composition of the liquor varies but slightly for the different grades. Salt and sugar are added to bring out the flavor, the tendency in some cases being to increase the sugar added to the higher grades.

(1) *Fancy.*—Prime material; uniform and tender in quality; of good flavor and color, and carefully prepared. In case of products packed in brine, the liquor should be clear or only slightly turbid.

(2) *Standard.*—Field run, of good stock, and of less uniform selection than (1). There may be slight discoloration, or breaking, due to processing. Sometimes there is an extra standard grade between (1) and (2).

(3) *Substandard, offstandard, or seconds.*—Wholesome, nutritious material, below (2) in quality.

LABELS.

The inspector should examine carefully all the labels used. Compare the statements on the labels with the facts developed by the inspection. Are the labels truthful in every detail? Is the quantity of contents in the cans stated correctly or does the label state that there are 1 pound and 4 ounces in the can when it contains only 18 or 19 ounces? Is the statement of the quantity of contents plain and conspicuous? Does the label bear any extraordinary claim as to the quality or grade of the food in the can not borne out by the facts developed by the inspection? Is the name of the canner correctly given upon the label? If the name of any firm or person other than the canner is placed on the label, it should be qualified by such words as "packed for" or "distributed by," to indicate that it is not the name of the canner. If any substance has been substituted in whole or in part for the substance named on the label, is there any indication of this fact upon the label? Does the label show that waste materials,

uch as trimmings, stems, and cores, have been used when such is the act? If certain varieties of fruits or vegetables are specified on he labels, the inspector should ascertain whether or not those varieies are actually in the can.

The inspector should familiarize himself with all the decisions nd regulations on labeling issued under the law which he is enorcing. He should study the labels in the cannery in the light of ie facts developed by his inspection to determine whether all the egulations and decisions are being complied with. The time of ispection is the time to check statements on the labels, for they an be verified then.

Copies of all the labels used on the different grades and cans of arious sizes put out by the cannery being inspected should be obined. These should be dated, identified, and attached to the facry inspection report, so that the reviewing officer may have them efore him when examining the report.

EMPLOYEES.

The appearance of the employees of a canning factory is an inex of the conditions the inspector may expect to find throughout ie factory and also an indication of the cleanliness and quality of ie finished product. Is there a sufficient number of unskilled labor-s for cleaning, scrubbing, disposing of waste, moving raw material, nd the like? Do the employees generally appear to be alert, quick, nd intelligent? Cleanliness and tidiness of their clothes will tell ie observing inspector much.

What precautions are taken by the manager to see that the emloyees are free from all contagious diseases? People with running res are especially unfit for employment where food is handled. Is iere evidence of any tubercular or venereal disease or the like? eport the total number and the sex of all employees.

CLEANLINESS.

A wholesome, sound food product can not be produced in an unean establishment. Cleanliness relates directly to the health of the nsumer. No matter how good the raw material may have been at e start, if cleanliness is neglected during the canning process the od in the can is likely to be contaminated, and there is always the obability that it may be dangerously contaminated. Furthermore, is is one of the features that can not be detected by the consumer examining the can.

While the sanitary features are important in all food factories. iey are of greater importance in some kinds of factories than in hers. For instance, in the inspection of a mill feed factory, cleanliss is of less importance than the facilities that the manufacturer

has for mixing and adulterating his feeds; on the other hand, in a cannery cleanliness is of first importance. In every step of his work, the inspector should give careful attention to this feature. An elementary knowledge of the conditions favorable to the growth of microorganisms will greatly aid him in making efficient inspections. The cleanliness which satisfies many housekeepers and many managers of canning plants is not usually sufficient from the point of view of the food inspector. Unless they are clean, small crevices, nooks, and corners become breeding places for millions of microorganisms.

The canning industry is widespread. A great deal of canning is done in small canneries near the fields where the fruits and vegetables are produced, where adequate water supply and drainage facilities may be lacking. The canner does not always appreciate the necessity for sterilizing his apparatus and for maintaining that degree of cleanliness which insures a wholesome product. The specialists of the Bureau of Chemistry have sometimes found conditions far from satisfactory on the premises of canners who sincerely believed that they were doing everything necessary to keep their canneries in a first-class, cleanly condition. Examination revealed many sources of contamination. In many instances the canners have expressed surprise when the possibility of contamination through such sources has been pointed out. The inspector should make a very careful examination of every factor that has a bearing on this important point. A general survey of the whole process and equipment will at once reveal flagrantly unclean practices or conditions, but very close inspection is required to find the sources of danger in those places which are on the border line and which to outward appearance are clean.

Walls which are either painted white or whitewashed are a great aid in keeping the cannery clean, making the rooms lighter and so revealing any cobwebs or dirt. Wooden floors should be water-tight to prevent refuse from getting under the building where it will undergo fermentation, thus producing bad odors and an insanitary condition that will render ineffective every other precaution for cleanliness. Floors in certain parts of the factory must be scrubbed and flushed frequently, an added reason for having water-tight floorings.

The inspector should observe the cleaning equipment on hand. This is in itself an index to the cleanliness of the cannery. Note the water taps, their number, and how conveniently they are located for cleaning all parts of the factory. Is the hose supply adequate? Note the number and kinds of scrub brushes and brooms. Brushes should be stiff, of split rattan or steel-wire bristles. Live steam, while essential for cleaning, is not sufficient alone to insure cleanliness. Stiff scrubbing brushes or brooms must also be used. Mold stick

ing to the woodwork may not always be removed by the application of steam, but it usually yields to a good stiff brushing. Painters' triangles are very useful for cleaning crevices and corners which can not be reached by a brush. The inspector will find a flashlight very useful in examining dark places where dirt is most likely to occur.

Special attention should be given to the method of disposing of waste, including parings, trimmings, cores, and the like. If any part of these trimmings are utilized in canning, the inspector should find out exactly how and ascertain whether the labels of the finished product bear a statement which shows clearly that they are made in whole or in part of such trimmings. The waste of a cannery should never be allowed to accumulate about the premises. Examine drains, sewers, and other means for disposing of such waste. Observe whether plumbing and sewer pipes are trapped effectively.

Give special attention to the toilets. Only those of modern, sanitary construction should be near the factory. Ordinary outside toilets should be a safe distance from the cannery, with their vaults screened against flies, and meet other sanitary requirements. Disinfectants should be used liberally. Make sure that the water supply to the cannery can not be contaminated from this source.

Ventilation is essential to the sanitary condition of the factory and to the health and comfort of the employees. Note the number, size, and location of windows and doors. Observe the number and kinds of ventilators in the roof. What provision is made for the elimination of escaping steam?

Plenty of natural light, which is an excellent disinfectant, not only contributes to the sanitary condition of the cannery, but is essential to the most efficient work of the employees.

Every cannery should have an abundant supply of pure water, and the inspector should carefully inquire into its source. Is it from streams that might be polluted? Shallow wells are not desirable because the water in them may become contaminated from surface drainage. If there is any suspicion as to the condition of the water, the inspector should consider the advisability of taking a sample for bacteriological analysis. Specific instructions for collecting such samples can be obtained from bacteriologists. In order to make thorough cleaning possible, the water used for this purpose should have a high pressure.

TOMATO-CANNERY INSPECTION.

More canneries handle tomatoes than any other single fruit or vegetable, and, as a rule, tomato canneries vary more than the others in processes, cleanliness, and equipment, and in the quality of the fin-

ished product. A large number of small tomato canneries are run by proprietors who have little knowledge of sanitation or the technique of canning. Canned tomato products have been the basis of more actions under the Federal Food and Drugs Act than has any other single product.

TYPES OF TOMATO PRODUCTS CANNED.

There are two general types of canned tomato products: (1) Tomatoes canned whole or in solid pieces; and (2) tomato pulp, purée, or paste, and similar products. Some canneries put up both types, using the best grade tomatoes, of uniform size, for the first, and the less desirable tomatoes, sometimes the trimmings, for the second class. Most canneries, however, put up only whole tomatoes, and a few are devoted exclusively to the manufacture of ketchup, pulp, purée, and the like.

SUITABLE TOMATOES.

Tomatoes best suited for canning whole or in solid pieces are smooth, making it possible to peel them easily, and have a clear, ruddy color. It is desirable to have them of moderate, uniform size and regular in shape. Some varieties which are fairly uniform in shape and size are much better adapted for canning than other varieties. The smaller and misshapen tomatoes may be used for making pulp and purée.

While the food inspector should report the varieties used, he is much more interested in the factors which affect the cleanliness and purity of the finished product, such as the degree of maturity, the absence of decayed spots, and the freedom from mold. Is the meat of the tomato firm, pulpy, or watery? Are there any sunburned spots, insect ravages, or evidences of blight?

Tomatoes should be picked frequently and delivered promptly to the cannery. Good tomato crates are wide and flat rather than deep. Tomatoes become bruised or crushed when delivered in deep boxes and when subjected to rough handling. Ripe tomatoes deteriorate quickly, so that it is a great advantage to have them grown near the cannery and handled promptly at every stage.

WASHING.

Washing is the first operation in many tomato canneries. The inspector should note the type and make of washer used and how efficiently the washing operation is performed. According to Howard and Stephenson (U. S. Department of Agriculture Bulletin 569), the principal types of washers in use are the following:

The apron washer.—This carries the tomatoes on an openwork apron through an inclosed chamber where strong sprays strike the tomatoes at different angles.

The rotary washer.—This consists of an inclined cylinder covered with a wire screen of 1-inch mesh. It will remove some of the soft-rot tomatoes as well as the dirt, but has a tendency to crush some of the very ripe tomatoes.

The paddle agitator.—This consists of slowly revolving paddles in a tank of water which cause the tomatoes to rub against one another, thus loosening the dirt. The tomatoes are gradually worked along toward the conveyor, which removes them from the tank and passes them under sprays of water which give them a final rinsing.

The air-blast washer.—This produces agitation and movement of the tomatoes by blasts of air entering the tank at or near the bottom. Otherwise it is similar to the paddle agitator type.

The cascade washer.—This has a tight-bottomed conveyor inclined at an angle of 30° to 50°, which carries the tomatoes upward. A stream of water flows through inlets near the top, down over the ascending tomatoes.

Many variations of these types of washers are put out by different manufacturers. The inspector should carefully observe the tomatoes after they come from the washer in order that he may determine how effective the washing process has been.

PEELING AND TRIMMING.

After being washed and scalded, the tomatoes for canning are usually delivered to the peelers by belts, by movable table tops, or in pails or pans. They are peeled and cored, and rotten spots or other undesirable parts are removed. Note the cleanliness and state of health of the peelers. Observe the cleanliness of the utensils used in carrying the peeled product from the peelers and the method of disposing of waste. Ascertain definitely whether or not the trimmings are used in the manufacture of pulp or paste, and if so, what care is taken to eliminate all rotten or unfit parts from the trimmings. All buckets or pans used for handling the peeled tomatoes should be kept clean. All tables or conveyors in which the peeled tomatoes are placed should be thoroughly washed when the plant shuts down at noon and at night, and stops should be made for this specific purpose at other times, if necessary, to keep them in first-class sanitary condition.

FILLING.

Tomatoes are put in the cans either by hand or by machines. When they are packed by hand, the sanitary or open-top can is used. Note the kind of filling machine, several types of which are made. Cans filled by hand are sometimes weighed in order to regulate the amount put in each one. When machines are used the inspector should note the size and capacity of the filler employed and give special attention to the method of controlling the quantity put in

the can. Are the cans in which the tomatoes are placed perfectly clean? Ascertain particularly whether any water is added to the product. Look out for short weight, slack fill, and the addition of pulp or purée.

PROCESSING.

Note the method, time, and temperature of exhausting and the method of sealing and processing. Report the make, size, and capacity of the machine used. What is the time, the pressure, and the temperature at which the processing is done? Is a number assigned to each batch processed?

TOMATO PULP.

Tomatoes which are to be made into pulp or purée, for use in the manufacture of ketchup or soup, are sorted by hand, usually before scalding, and put through a cyclone which crushes them into a pulp and eliminates the seeds, cores, and peelings. The essential point to be observed by the inspector is that no wholly or partially dirty, moldy, or rotten tomatoes go into the cyclone. Tomato pulp and purée are of such a nature that as much as 20 per cent of decomposed matter may be present without being detected by the consumers. Since the complete elimination of rotten material is expensive, the temptation for the canner to become careless in this respect is ever present.

PULPING.

The most essential thing for the inspector to ascertain in the pulping operation is the kind of material from which pulp, purée, or paste is made. What precautions are taken to eliminate the rotten and other undesirable parts? Efficiency in washing and a most careful sorting are essential in securing a good product. It is also highly important that tomato stock be handled promptly at every stage. Pulp is an ideal field for the growth of bacteria, molds, and yeasts. Molds sometimes grow on conveyors and on cyclone paddles, as well as in more out-of-the-way places. Their presence always indicates a lack of thoroughness in cleaning. The inspector should give special attention to the conveyors and pipes through which the pulp flows in order to determine their accessibility for cleaning, as well as by what means and how thoroughly they are cleaned in actual practice. He should also find out the degree of concentration of the pulp and how it is regulated.

Valuable information on the making of pulp and the canning of tomatoes is given in United States Department of Agriculture Bulletin 569, "The Sanitary Control of Tomato-Canning Factories," copies of which may be obtained by application to the Division of Publications, United States Department of Agriculture, Washington, D. C.

INSPECTOR'S REPORT.

PURPOSE.

The report of the inspector giving the results of his observations during a cannery inspection serves as the basis for action by the administrative officers. The report should present a clear picture of the sanitary condition, equipment, processes, and labels of the cannery, so that the reviewing officer can determine whether or not the cannery and its output meet the requirements of the law which he is administering. The report should be clear in every particular, leaving no doubt upon any point. In making his report the inspector should be as fair as is humanly possible—fair to the proprietor of the cannery, fair to the administrative officer under whose direction he is operating, and fair to the people for whose benefit food laws are enacted.

ASSEMBLING FACTS.

Report all pertinent facts and be sure of all the facts reported. No subsequent action on the part of the inspector can make amends for carelessness in this respect. While it is not practicable to take elaborate notes of all the details observed at the time of making the cannery inspection, the inspector should make such notes as may be necessary to insure a complete and accurate report. It is well for him to assemble his facts, and, where possible, to complete his report while in the town in which the cannery is situated, so that, should he find that he has missed some important details or is not certain of some pertinent fact, he can secure the additional information or verify the fact.

EMPHASIS.

Some facts observed by the inspector will be of more importance than others in passing judgment upon a particular cannery. Emphasize the pertinent points, but keep in mind the fact that the particular points upon which emphasis should be placed vary in different canneries. The purpose of emphasis is to more clearly set forth the truth. If the inspector's observation has shown him that a cannery is not in a sanitary condition, facts which go to show that condition should be brought out clearly. There is, of course, danger of overemphasizing unimportant things in a measure that will mislead the reviewing officer. But if the inspector remembers that the purpose of emphasis is to give the reviewing officer a clear idea of the factors that make the cannery's condition good, bad, or indifferent, as the case may be, he can use the principle of emphasis to advantage and avoid burying the essential facts of his report under a mass of irrelevant matter.

102636—22——3

FORM.

The following form, with appropriate headings for reporting the inspection of a pea cannery, illustrates a method for reporting a cannery inspection. Such a form is suggestive, and not to be followed as an iron-clad rule. The report should be made in detail on blank sheets, properly paragraphed under suitable headings. Any of the headings here listed which are not applicable to a particular cannery may be omitted and pertinent points other than those indicated on the form may be treated on additional sheets under appropriate headings devised by the inspector.

(1) GENERAL:
- (*a*) Date of inspection.
- (*b*) Name of proprietor.
- (*c*) Post office address (cannery office).
- (*d*) Legal status of proprietor (independent owner, partnership, corporation).
- (*e*) Subsidiary or related firms.
- (*f*) Products canned.
- (*g*) Amount of output.
- (*h*) Territory in which output is distributed (names of consignees of recent shipments).

(2) CANNERY BUILDINGS:
- (*a*) Number and construction of buildings.
- (*b*) Surroundings.
- (*c*) Kind and condition of floors, walls, and ceilings.
- (*d*) Light.
- (*e*) Ventilation.
- (*f*) Facilities for cleaning.

(3) SANITARY AND COMFORT FEATURES:
- (*a*) Drainage and sewage system.
- (*b*) Kind and condition of toilet, wash, rest, and dressing rooms.
- (*c*) Is factory screened or otherwise protected against outside dirt, flies, etc.?
- (*d*) Water supply, source, volume, etc.

(4) EMPLOYEES:
- (*a*) Number.
- (*b*) Sex.
- (*c*) Health.
- (*d*) Cleanliness.
- (*e*) Dress.
- (*f*) Character of work.

(5) GROWING AND HARVESTING THE PEAS:
- (*a*) Varieties, seed.
- (*b*) Planting, successive control, possession farmer or factory.
- (*c*) Maturity.
- (*d*) Time cut vines lie in field.
- (*e*) Radius of haul.
- (*f*) Season, frost, etc.
- (*g*) Field damage.
- (*h*) Mowing, harvesting.
- (*i*) Disease, insects.

(6) PEA VINER:
- (*a*) Type and make.
- (*b*) Rented or owned.
- (*c*) Location, field or factory.
- (*d*) Construction.
- (*e*) Cleaning.
- (*f*) Box containers.
- (*g*) Amount of damage to peas.
- (*h*) Ensilage, vines, composition.
- (*i*) Control of deliveries to viner, weight of loads.
- (*j*) Deliveries of shelled peas.
- (*k*) Disposition of refuse that does not enter ensilage.

(7) SHELLED PEAS:
- (*a*) Weighing of shelled peas.
- (*b*) Price paid per pound for shelled peas.
- (*c*) Storage of peas before processing.
- (*d*) Cleaner or clipper, make, disposition of tailings.

(8) WASHER:
- (*a*) Make.
- (*b*) Description, "squirrel cage," etc.
- (*c*) Results obtained.

(9) CONVEYORS:
- (a) Belts, spouts, pails.
- (b) Galvanized, wooden.

(10) SORTING AND REMOVAL OF DEFECTIVE AND IMPERFECT PEAS:
- (a) Tables, gravity, moving belt.
- (b) Rejects.
- (c) Completeness of work.

(11) GRADING:
- (a) Name and description of grades put up.
- (b) Gravity solutions, formula, specific gravity.
- (c) Rotary screen, make, meshes.
- (d) Sizes (page 34).

(12) BLANCHING:
- (a) Make of apparatus.
- (b) Temperature.
- (c) Time.
- (d) Revolutions.
- (e) Soda; if used, give formula showing percentage amount.
- (f) Are all grades given same blanch?
- (g) Results obtained.

(13) CANS:
- (a) Make.
- (b) Size.
- (c) Variety.
- (d) Cleaning.
- (e) New or old.

(14) FILLER:
- (a) Make.
- (b) Size and capacity.
- (c) Adjustments, for different grades.
- (d) Are consecutive deliveries uniform in weight? If not, to what are variations due?

(15) BRINER:
- (a) Formula, kind of sugar and salt.
- (b) Variations in the liquor or sirup.
- (c) Amounts added.
- (d) Temperature.
- (e) Absorption of brine.
- (f) Flavor or preservatives.

(16) SEALER:
- (a) Make.
- (b) Capacity.
- (c) Description.
- (d) Acid, solder.
- (e) Efficiency.

(17) PROCESSING:
- (a) Retorts or sterilizers, make, grouping capacity, operation.
- (b) Time bringing up to maximum temperature and pressure.
- (c) Time held.
- (d) Pressure.
- (e) Swelling of peas during processing or cooking.
- (f) Results obtained.

(18) COOLING:
- (a) Method employed.
- (b) Retorts.
- (c) Tanks.
- (d) Results obtained.

(19) PROMPTNESS IN HANDLING.

(20) FINISHED PRODUCTS:
- (a) Mark on cans with key.
- (b) Storage.
- (c) Amount of output; R. R. facilities.
- (d) Capacity.
- (e) Price list.
- (f) Shipments, local, interstate, export.
- (g) Distribution.

(21) FILL OF CAN:
- (a) Each grade, weight of cans—
  - Empty.
  - Sealed, filled.
  - Brine, drained from filled can.
  - Peas, drained from filled can.
- (b) Amount of peas necessary to fill can.
- (c) Variations filling machine.
- (d) Scales used.

(22) QUALITY:
- (a) Maturity.
- (b) Flavor.
- (c) Color.
- (d) Uniformity, mixed.
- (e) Turbidity of liquor.

(23) WASTE:
- (a) Vines and peas.
- (b) Spilled peas on floor.
- (c) Picking tables.
- (d) Material removed from interior of viner, cleaning.
- (e) Blancher liquor.
- (f) Defective cans, swells and returned, percentages applicable to various grades.
- (g) Injured peas in viner and clipper, percentage.

(24) PERSONS INTERVIEWED.
- (a) Name and attitude of each.

(25) EXHIBITS:
- (a) Photographs, description, and designation of those attached.
- (b) Labels, description, and designation of those attached.

(26) REMARKS AND RECOMMENDATIONS, INCLUDING ADDITIONAL SUBHEADS AND POINTS FOR SPECIAL EMPHASIS.

POINTS FOR SPECIFIC PRODUCTS.

The statements regarding processes in this section, especially those specifying time and temperatures, are based upon the observations of inspectors in certain commercial canneries. They do not necessarily describe the ideal processes and no recommendation is made or implied that they should be followed. They are set forth to give the inspector an idea of what is done in commercial canneries, rather than to furnish canners with information on the best processes.

FRUITS.

APPLES.

Since some varieties keep well in their natural state, the canning of apples is perhaps of less importance than the canning of other fruits which constitute a smaller part of the diet but do not keep well unless dried or canned. The chief varieties of apples canned are Baldwin, Greening, Spy, and others of the better fall and winter apples. The summer apples turn soft and mushy in the can. The chief grades are the fancy, standard, and pie. The fancy grade is put up in sirup, the degree of sirup varying in different canneries. The best seller is the No. 10 can, packed in water for pies.

Canned apples should be prepared from matured, sound fruit, thoroughly washed and cleaned, well peeled, cored, and free from decay, bruise, or discolor, and damage caused by disease or insects. The peeling and coring may be done either by hand or by machine.

The inspector should determine the character, quality, and disposition of the waste from apple canning.

APRICOTS.

The canning of apricots is principally a California industry. The season extends from June 15 until about September 1, being heaviest in July. The chief varieties of apricots for canning are the Blenheim and the Moorpark.

The fruit is washed, the pits are removed by hand, and the fruit is graded as green, regular, and ripe. The green and regular grades are further graded in 6 sizes by being passed over copper screens having perforations which vary $\frac{1}{8}$ inch in the different sizes. The largest perforation is $1\frac{7}{8}$ inches in diameter and the smallest is $1\frac{3}{8}$ inches in diameter. The smallest grade is made up of apricots that pass through the $1\frac{3}{8}$-inch screen, and the largest is composed of those that pass over the $1\frac{7}{8}$-inch screen. Fruit of each size is conveyed, usually by belt, to a packing table designated for that size, and dumped into troughs containing clear, cold water. Pieces which are spotted or rough or imperfect in shape are packed in separate cans as a rough grade. As the ripe fruit is usually too soft to stand being passed over the grader, it is graded and packed by hand. It brings a slightly higher price than the other grades.

The cans are next conveyed to the siruping machines, where they are filled with sirup of the proper degree, ranging from 55° in the highest grade to 10° in the lowest grade in which any sirup is used. They are then exhausted, sealed, and cooked for the necessary period of time. The water grade is packed in water. The pie grade, which usually consists of overripe and broken pieces and any pieces unsuitable for the other grades, is packed in water. Some canners are now putting up a "solid-pack" pie fruit, that is, apricots packed solid in the can without the addition of water or sirup. A large pack of apricots peeled by hot lye solution (p. 25) is also made.

The inspector should give special attention to the water and pie grades, making sure that no floor sweepings or decayed or wormy fruit have entered the cans. Since apricots are handled a great many times by hand, the cleanliness and health of the workers and the sanitary conditions of the factory are important factors.

BERRIES.

The principal berries canned are strawberries, loganberries, gooseberries, and blueberries. There is a great variation in the grade of berries. In some localities little grading is done, and not more than three grades are put up anywhere except in California, where some canners use the following scheme of grading: Special extra, put up in 60° to 70° sirup; extra, put up in 40° sirup; extra standard, put up in 30° sirup; standard, put up in 20° sirup; seconds, put up in 10° sirup; and water or pie, packed in water.

Strawberries.—Strawberries are usually delivered to the canneries in shallow boxes or small baskets, dumped into small trays or pans, and carried to tables where they are capped by hand and sorted into three, four, or more grades according to the practice of the cannery. As a general rule, three grades are packed, special extra, standard,

and water or pie. Strawberries are or are not washed to remove sand and dirt, according to the practice of the individual cannery. The washing consists of a quick rinsing in pans or sinks of cold water or by a light spray. The berries are then removed by hand and placed in cans. Lacquered cans are generally used in order to better retain the color of the berries. Overripe strawberries are not washed. The sirup or water is then added, and the cans are exhausted for from 3 to 5 minutes at about 212° F. The No. 2 cans after capping are processed in continuous cookers for from 8 to 10 minutes at about 214° F. or for from 10 to 17 minutes in open cookers at 210° to 212° F. A longer period for exhausting and cooking is required for the No. 10 cans. From the cooker the cans are placed in tanks of cold water to stop the cooking and reveal the presence of any leakers. After packing some canners weigh each can, then exhaust for 5 or 6 minutes, and add sugar in definite quantity. Then the cans are filled with boiling water, capped, and processed. Under this method it is necessary to agitate the cans in some manner during the cooking period.

Loganberries.—Great care is used in handling loganberries, which contain a large percentage of juice and are exceedingly delicate and easily bruised. In a few canneries the berries are washed by being dipped for an instant in cold water, but in the majority of canneries they are neither dipped nor sprayed with water, for the reason that such treatment might remove a portion of the juice. The operations of sorting, grading, and filling the cans are usually performed by girls. It is now customary to weigh a definite and uniform amount of fruit into each can. Sanitary type cans, enamel lined, are used. The firm berries are usually segregated into two sizes and dropped into two sets of cans, No. 2 and No. 2½. The bruised and soft berries are packed in No. 10 cans as water or pie grades. Hot sirup of proper density, or water as the case may be, is added to the cans which are then passed through the exhaust box, capped, seamed, and sterilized. The No. 2 and No. 2½ cans receive a 3-minute exhaust and the No. 10 cans a 10-minute exhaust, the temperature in each case being from 180° to 190° F. The processing varies according to the style of equipment. Where agitating steam cookers are used, the No. 2 and No. 2½ cans are processed for 3 minutes, and the No. 10 can for from 8 to 16 minutes, according to the quality of the fruit. The temperature of the cooker is maintained at from 214° to 215° F. Where the processing is accomplished by placing the cans in boiling water, the time necessary for sterilizing is materially increased, being from 8 to 14 minutes for the No. 2 and No. 2½ cans and from 25 to 40 minutes for the No. 10 cans, depending upon the ripeness of the fruit. Loganberries are put up in the usual commercial grades. In making

inspections, attention should be given to the condition of the fruit as delivered to the cannery, whether fresh and clean, or soft, dusty, and possibly moldy, to the care taken for maintaining proper and uniform fill of cans, and to the general methods of labeling.

Blackberries.—Blackberries are handled in much the same way as are strawberries. All grades are packed in No. 2 cans and a small quantity of some grades is packed in No. 1 cans. About 75 per cent of the entire pack is water grade and put up in No. 10 cans. Blackberries are not washed unless they happen to be particularly dirty. The special extra grade generally takes a 40° or 50° sugar sirup. Other grades follow the usual custom.

Blueberries.—The canning of blueberries, among the few wild fruits canned, is confined chiefly to the State of Maine, although small quantities are put up in other States. The berries are cleaned by blowing out the leaves and stems by machines and by hand picking. Most of them are packed in No. 2 and No. 10 cans. Canned blueberries are used almost exclusively for pies.

Gooseberries.—At the cannery gooseberries are first run through a snipper to remove the stems, then dumped into tubs or pans of cold water from which they are picked by hand and graded. Size, firmness, and appearance are the qualities chiefly considered in making a special extra grade. The only other grade packed to any extent is the water grade. Gooseberries are placed in cans by hand and treated like other berries. The special extra grade is usually put up in a No. 2 can, and the water grade in a No. 10 can.

Raspberries.—The canning operations for raspberries are very similar to those for strawberries. Raspberries are graded according to size and firmness. The bulk of the pack is marketed in a special extra grade, in No. 2 cans, taking a 50° or 60° sugar sirup. The water grade is packed in No. 10 cans. Raspberry bushes are sufficiently erect to protect the fruit from soil contamination, so that the berries are fairly clean and it is not customary to wash them.

CHERRIES.

Both sweet and sour cherries are canned, the former principally on the Pacific Coast, and the latter in Michigan and New York. Sweet cherries are usually packed unpitted, while the sour cherries are usually pitted. After delivery to the canneries in lug boxes, the cherries are run through a washer, stemmed by hand or by a machine stemmer, and worked over a machine which grades to size. The different sizes are carried to tables where the cans are filled by hand. Cherries are pitted by machine. All the usual commercial grades are packed, principally in the No. 2½ cans, although No. 2 and No. 10 cans are also used. After the addition of sirup or water,

according to the grade, the cans are exhausted for from 3 to 5 minutes, capped, and processed in open or continuous cookers for from 20 to 25 minutes, after which they are cooled in a water bath.

The inspector should watch out for an excessively large number of pits in canned cherries.

FIGS.

Figs are sorted by size. No definite grades for them have been established. After the rough portion of the skin is removed, the figs are heated with sugar in jacketed kettles, so that the sirup becomes so heavy that they are nearly a preserve. They are packed in 4-ounce, No. 1, No. 2, and No. 10 cans, and in individual glass containers.

GRAPES.

Two varieties of grapes are principally used for canning, the Muscat in the west and the Niagara in the east. Only a comparatively small quantity of grapes is canned, and that chiefly for use as pie fruit. The grapes are stemmed by hand, machine graded to size, washed, and placed in cans. After the addition of hot sugar sirup or water, the cans are capped and processed for about 14 minutes at 212° F. in open or continuous cookers. The bulk of the pack is water or pie grades, although small quantities of the other commercial grades are put up by a few canneries.

OLIVES, RIPE.

The canning of ripe olives is confined almost exclusively to California, although small quantities are put up in Arizona. The olives are usually graded in five or more sizes, those smaller than 9/16 inch in diameter generally being used for making oil. The size graduations are usually made on a difference of about 2/16 inch. The California Olive Association has adopted the following grades:

Olives to the pound.	Grade.
120–135	Standard
105–120	Medium
90–105	Large
75– 90	Extra large
65–75	Mammoth
55–65	Giant
45–55	Jumbo
35–45	Colossal

The olives are first taken to pickling vats, where a quantity of 1½ to 2 per cent caustic soda solution, in weight about 5 times that of the olives, is poured over the fruit, and allowed to stand for from 6 to 8 hours with frequent stirring. This liquor is then drained off and the olives are exposed to the air for 24 hours, with occasional stirring. More of the same or a weaker solution is applied for an equal length of time and again run off and the fruit aerated. This operation is performed a third time, or until the caustic reaches the pit, as indicated by a darkening of the flesh. The lye solution is then run off

and fresh water is added to the vat. The water is changed about every 12 hours until all the lye is washed off. At this point the salting of the olives is begun by introducing them into a solution of brine of gradually increasing strength of about 1, 2, and 4 per cent salt. The complete operation requires from three to four weeks' time. The olives are soaked about two days in each of the different solutions, after which they are canned in a 3 or 4 per cent brine and sterilized.

The inspection should determine whether the olives labeled as ripe are fully ripe. If the olives are held in brine solution before canning, examine for evidence of bad fermentation and objectionable odors. If minced olives, olive paste, or similar products containing minced olives are made, pay particular attention to the quality of olives entering the product. Ascertain especially the temperature used in sterilization and the periods of time employed for the packages of various sizes and what factory means are used for temperature control. Pickling rooms should be free from mashed and spoiled olive litter; the floors should be clean and so constructed that they may be kept so. Are the vats free from scum or filth and do any of them contain spoiled, mushy, or soft olives? What disposition is made of the spoiled and damaged olives? Are they removed to a safe distance from the factory?

PEACHES.

While peaches are grown in nearly all parts of the United States, most of the canned peaches come from California and Georgia. Some varieties of this fruit are not suitable for canning. The following varieties are canned: Foster, Muir, Lovell, Salway, and Yellow Free or Yellow Crawford, all of which are freestone peaches, and Phillips, Tuscan, Johnson, Walton, and Albright Cling, all of which are clingstone varieties. Peaches should be canned as soon after picking as possible. They are first pitted and then peeled by hand, by lye, or by slipping the skins. Nearly all the peaches canned in California are lye peeled. They are carried on belt conveyors through a peeling lye solution containing from one-half to 1 pound of concentrated lye to a gallon of water, then through several automatic washing machines containing cold water. To prevent darkening of the product and to make the fruit more flexible, so that a better fill can be obtained, peaches are heated or blanched for a few minutes. Blanching, however, is unnecessary if the peel has been removed by lye peeling or slipping the skins.

After being halved, the peaches are passed over a series of grading screens having meshes $1\frac{3}{4}$, $1\frac{7}{8}$, 2, $2\frac{1}{4}$, and $2\frac{3}{8}$ inches, respectively, in diameter, which divide the fruit into six sizes, those passing through the $2\frac{3}{8}$-inch mesh constituting the highest grade. Overripe and

underripe fruit and that which must be trimmed extensively to remove blemishes is packed as second, water, or pie peaches.

The cans are filled by hand. Peaches in No. 1 cans are exhausted for 1½ minutes and processed for 15 minutes at 212° F. Those in No. 2½ and No. 3 cans are exhausted for 3 minutes and processed for 20 minutes at 212° F. Those for No. 10 cans are exhausted for 5 minutes and processed for 35 minutes at 212° F. These figures vary according to the degree of ripeness of the fruit. The time is materially shortened by the use of an agitating cooker. All the usual commercial grades are put up. The sirup runs from 55° in the highest to 10° in the seconds, and no sugar is used in the water or pie grades.

Special attention should be given to the matter of the fill of the can and to the cleanliness and health of the employees.

PEARS.

All work on pears is done by hand because of their peculiar shape and texture. They are graded, peeled, cored, and packed in halves. The special extra grade is of such a size that 8 or 9 pieces will fill a No. 2½ can, evenly matured, of fine texture, perfectly peeled and cored, and packed in 40° sirup. The extra grade has the same qualities, but may have from 9 to 12 pieces to a can and be put up in 30° sirup. The extra standard has the same qualities, but may have from 10 to 14 pieces in the can, with a 20° sirup. The standard grade is a pear of good quality but less uniform in size, color, and quality than the preceding grade. More tolerance is permitted in peeling and coring, and a 15° sirup is used. Seconds consist of small soft pears, cut in irregular pieces, and packed in 10° sirup. The lowest grade has the same quality as the seconds, but is packed in water. Pears are packed in No. 1, No. 2, flat No. 2, No. 2½, and No. 10 cans.

Since a great deal of the work on pears is done by hand, the inspector should give special attention to the cleanliness and health of the employees.

PINEAPPLES.

The pineapple industry is confined chiefly to the Hawaiian Islands, although pineapples are canned in a few places in the United States. The fruit is harvested by hand. It is usually necessary for men to go over a given field several times, gathering each time only those pineapples that are in proper condition for shipping and canning. The cut fruit is gathered in piles at the end of rows and there graded as No. 1, No. 2, and No. 3, according to the weights. A good grader needs no scales, as his eye and hand become very accurate. The fruit is carefully placed in heavy wooden boxes and transferred to the cannery, where it is trucked to the various sizing machines in ac-

cordance with the grading already done in the field. These sizing machines square the ends of the fruit, remove the shells in three pieces, cut out the cores in cylindrical form, and size the fruit to fit the can.

The cored and sized fruit drops onto a conveyor belt which carries it along the trimming tables. Standing on either side of the table the trimmers cut off any portion of the peel which may have been missed by the sizer. After being trimmed, the fruit is returned to the belt and carried to the slicing machine, where it is cut crosswise into disks or slices. The slices are then passed along the conveyor belts to the packing tables, where the different grades are sorted out and packed in cans.

Essentially four different grades or classes of fruit are packed. In the fancy grade, the slices must be cored perfectly, with no bit of the peel remaining and no imperfections from trimming cuts on the outer edge. The fruit must be fully ripe, with a good, rich color. In the standard grades the slices need not be perfectly cored, and they may have one or two slight imperfections on the outer edge. The color of the fruit of this grade may be a little less rich than that of the fancy grade pineapple. The fruit, however, must be good. The third or substandard grade slices are those that are not suitable for the first two grades but have not been broken to pieces. A slice with a decided hole in the edge is sometimes packed as the third grade. The fourth grade includes cores, broken pieces, and grated materials, all of which are canned separately and labeled appropriately.

The packed and graded cans go to the sirup machines, where each grade receives a sirup of a different strength. The open cans of fruit are next passed through the open exhaust box, where they are held, according to different practices, for from 2½ to 6 minutes at the temperature of live steam. Immediately after being exhausted, the cans are passed on to the closing machines, where the covers are sealed on, sanitary seal cans being used in all cases.

Two general methods for sterilizing are employed. In one, the cans in large crates handled by cranes are placed in large open vats of water heated by steam coils. The cans are kept in the boiling water for from 30 to 40 minutes. In the second method there is some device for keeping the cans in continuous motion. The cans need be kept in the boiling water for only approximately 14 minutes.

One of the greatest problems in the pineapple industry is the utilization or disposition of the waste or by-product. The proportion of the whole pineapple that is not suitable for canning varies from 50 to 60 per cent. Attempts have been made to utilize the waste in various ways. The inspector should note whether any of it is allowed to ferment in or near the cannery.

PLUMS.

The Green Gage, Yellow Egg, and Damson plums are the principal varieties canned. Plums are packed when fairly ripe and soft. On account of the checking or cracking of the skins during processing many canners hold the fruit for several days, allowing it to wilt, which lessens the tearing of the skin and makes a more sightly pack. The fruit is first run over a grader and separated into four sizes, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, and $1\frac{3}{4}$ inches in diameter.

After the plums have been washed, the imperfect and spotted fruit is sorted out and the rest is packed in cans by hand. Plums are not peeled. A hot sugar sirup or water is added, and the cans are exhausted, capped, and processed in continuous cookers, for from 8 to 14 minutes, or in open cookers, for from 36 to 38 minutes, at about 212° F.

Plums follow the usual commercial grades for fruits and are packed in No. 1, No. 2, No. $2\frac{1}{2}$, and No. 10 cans.

PRUNES.

While prunes are usually dried, a large quantity is also canned, especially for shipping to the Tropics or to foreign countries. Usually three grades are packed. The extra grade is packed in 30° sirup, the standard grade in 20° sirup, and the lowest grade in water. They are put up in No. $2\frac{1}{2}$ and No. 10 cans.

VEGETABLES.

ARTICHOKES.

Artichokes are gathered by cutting off the bulb as close to the head as possible and they are delivered to the canneries in crates. Some canners use the whole artichoke; others remove the outer scales and often the tops of the inner leaves, leaving only the hearts. The artichokes are allowed to stand for 48 hours in a solution consisting of 5 per cent salt and one-half of 1 per cent citric acid in water. The acid is added to prevent discoloration. Vinegar is sometimes used in place of citric acid. The artichokes are next blanched for from 5 to 7 minutes in a hot, light brine solution, after which they are drained and placed in cans with fresh brine. The filled cans are exhausted, capped, and processed, as in the case of other vegetables. The time of processing varies with the size of the cans.

Three grades of trimmed artichokes are packed. The best consists of the largest of the most tender heads, which are trimmed down close and known as "baby hearts." The next grade includes the smaller and less tender heads. The third grade comprises all artichokes unfit for the other grades. They are packed in No. 2, No. $2\frac{1}{2}$, and No. 10 cans.

Inspection should show whether the blanching agents used are in violation of the law and whether the net weight is correctly stated.

ASPARAGUS.

More than 90 per cent of the asparagus canned in the United States is put up in California. The white stalks are more desirable for canning purposes than the green stalks.

The asparagus is cut, packed in lug boxes of about 40 pounds each, and hauled to the cannery by wagon or boat early in the morning. It is then sorted by women into two grades, green and white. Each color is next sorted by the women, usually into six uniform sizes, known as giant, colossal, mammoth, large, medium, and small. These names apply to the circumference of the stalk and not to the length. As the stalks are sorted, each size is stacked carefully, stem end out, in wooden boxes having one end open, the sides of which are slightly shorter than the height of the can into which the asparagus is to be packed. The women then cut off even with the box the protruding ends of the stalks. The asparagus is next dumped into wicker or wire baskets, blanched in boiling water, sprayed for a minute or so with cold water, conveyed to the packing tables, and dumped into troughs containing cold water. The women pack the stalks vertically in the cans. The cans are then filled with about 11° brine, exhausted, sealed, and cooked in retorts for varying lengths of time, according to the size of the can and the condition of the asparagus. The pack of tips only, that is, the top or blossom end of the stalks, is quite large. These tips are also graded into green and white and into five sizes. They are usually about 3 inches long and are packed in a No. 1 square tin in the same manner as the regular stalks.

Occasionally a fungus, called in the trade "rust," which produces a brown discoloration on the stalk, makes its appearance in certain districts. Some packers may be careless in handling the "soup tip," as a result of which many dirty or decayed pieces or trimmings are included, rendering it filthy and decomposed. Because of the fact that each individual stalk is handled by operators, particular attention should be paid to the sanitary conditions and to the cleanliness of the employees.

BEANS.

The principal varieties of beans used in canning are Refugee, Lima, Navy, and Red Kidney. Refugee beans are canned for their pods, which are fleshy, crisp, and tender, rather than for the seed. The beans are sorted by machine, according to their diameter, the larger ones being cut to definite lengths, and filled into the can by weight. They are packed in No. 2, No. 2½, No. 3, and No. 10 cans.

Wax beans are handled in the same manner. Lima beans are shelled and packed both green and ripe. The beans are graded for size by sieves. The Navy bean is the one most generally used in packing pork and beans. The Red Kidney bean is packed either plain or with tomato sauce. In general, beans are canned in the following four ways: With pork and tomato sauce; without pork and with tomato sauce; with pork and plain sauce; without pork and with plain sauce.

Usually beans are put up in at least three grades. Inspectors should give attention to the variety canned and check this up with the labels in use. There has been a tendency on the part of some canners to use the names of varieties which are in much demand for cans in which other varieties are packed. This has been particularly true of Red Kidney beans. Attention should be given also to the labeling of baked beans. Beans cooked by steam in cans should not be labeled " Baked beans."

A large proportion of the green Lima bean pack of the United States is grown and canned in New Jersey. The small Lima beans from the Bush Lima are used exclusively in four canneries which put up probably from 75 to 85 per cent of the entire pack in the United States. The procedure and machinery used in canning Lima beans are almost identical with those used in canning peas. The outline on pages 18 to 20 of this bulletin may be followed with little or no change.

After the Bush Lima bean vines are harvested, the beans are beaten out in a pea viner. The harvesting is done when the beans reach the stage of maturity at which the canner, who usually grows most of the beans he packs, believes he will get the greatest return from his crop. This is the condition when some of the beans are small and immature while others on the same or adjacent plants are so mature as to be white. As a result the shelled beans are a mixture of green and white beans. The beans are cleaned, washed, and graded into two or three sizes as described on page 33. Some canneries put up a portion of their pack as " field run," but all make an attempt to separate them. In some plants the separation is done imperfectly in a mechanical brine separator such as is used in pea canneries. This separator is not entirely satisfactory, but it reduces the quantity of whites to be removed by hand. In other plants the separation of whites is done entirely by hand picking.

The cleaned beans are blanched in hot water, then rinsed with cold water, and filled into the cans by machinery. The small green Lima beans require great care and attention to detail during the process in order to make sure that the cans shall be entirely full of beans and brine and the two so proportioned that the beans are just covered by a clear, transparent brine. Since beans of varying

maturity are canned at different times during the day as different parts of the fields are harvested, the operator must make corresponding changes in the time of blanching and in the quantity of beans delivered to the cans. The very small green beans require a short blanch, and, as they swell little during the final processing, a larger quantity of them is needed to fill the can. Conversely, the more mature white beans require a much longer blanch to attain a maximum swell. A perfect fill can be secured with the all-green beans in No. 2 cans, but it can seldom be reached with the white beans in No. 10 cans. It is impossible for the operator to put up a high-grade pack of beans without cutting the cans from time to time during the day and adjusting the time of blanching and the quantity delivered by the filler as changing conditions demand.

BEETS.

Beets are topped in the field and delivered in lug boxes to the canneries where they are first washed in cold water and then passed through a scalder. The roots are cut off and the outside skins are removed by hand. After rewashing in cold water, the beets are hand packed, whole, in slices, or in broken pieces, the slicing ordinarily being done by machines. The cans are passed through an exhaust box for from 5½ to 7½ minutes at a temperature of 212° F. After a hot, weak brine solution is added, the cans are capped and processed in a continuous agitating cooker for from 5 to 12 minutes, according to the size of the can and the character of the beets. In open cookers the time is proportionately longer. The canner aims to secure a bright rather than dark color in the finished product. The pack is graded as standards and seconds, the standard grade being subdivided into large whole, medium whole, and small whole, while seconds consist of pieces and broken slices.

Inspectors should give attention to the raw material used, to the fill of the can, and to the statement of the net weight.

CARROTS.

The tops are cut off in the field and the carrots are delivered to the canneries in lug boxes. After being washed in cold water they are either lye peeled or hand scraped, although some canneries run them through two weak lye solutions instead of one strong solution. They are then washed in cold water to remove the lye. The roots are cut off and the eyes trimmed out, after which the carrots are quartered, all by hand. They are then placed lengthwise in the cans and packed tight. After a 5½ to 7½ minute exhaust at 212° F., a hot brine is added and the cans are capped and processed in a manner similar to that used for beets. They are graded as standards or seconds, the latter consisting of short lengths and pieces.

The principal points to observe in making an inspection are the quality of the raw material, the composition of the peeling solution, the fill of can, and the statement of net weight.

CAULIFLOWER.

The commercial canning of cauliflower as a vegetable is limited, the bulk of the crop being preserved in brine for pickle packers. The salted cauliflower is washed to remove the excess salt, blanched, and sealed. Fresh cauliflower is boiled in hot salt solution and packed in tins while warm. The interstices are filled with a hot, weak salt solution and the cans are immediately sealed to prevent exposure to air and darkening of the product. Sterilization must be done carefully or the pack will be mushy, brown, and foul smelling.

The inspector should give special attention to the quality of the cauliflowers used for canning.

CORN.

Corn is canned principally in two styles. By the first, which originated in Maine, the kernels are cut off and the milky portion is scraped from what remains on the cob. The cut and scraped corn is mixed with a sweetened brine. The product is thick and creamy in consistency, showing no separation of liquor. Corn packed in this way in other places than the State of Maine is called "cream corn," and sometimes incorrectly "Maine style." The use of the term "Maine style" on corn packed in any State other than Maine is considered a misbranding under the Federal Food and Drugs Act. In the second, or Maryland style, the whole grains are packed in brine. Corn is delivered to the cannery on the ear. The husks are removed by machinery in the larger canneries and by hand in the smaller ones. The corn is then dropped on a conveyor, from which the defective and worm-eaten ears are picked out, the good part being sent to the trimmer. Corn is put up in four grades: Fancy; extra standard; standard; and substandard, or seconds.

Most of the work in the modern cannery is done by machinery, such as huskers, silkers, cutters, mixers, cookers, and fillers. The corn, handled by automatic machinery, after receiving a preliminary heating by steam, is evenly mixed with brine and packed in the cans. The corn enters the cans at about 180° F. and the capping is done in the usual manner. No. 2 cans are sterilized at a temperature of 250° F. for 80 minutes. Some packers process at 245° F. for 100 minutes, and others process twice to insure keeping, for corn is one of the most difficult foods to process.

The inspector should give particular attention to the character of the raw material used and to the fill of can.

HOMINY.

The selected white corn used in making hominy is shelled and then screened to take out all small defects or split grains and any chaff or foreign substances. It is next washed and given a treatment of hot solution of lye, during which time it is constantly cooked and agitated until the tough hull loosens. The strength of the lye and the length of time required for cooking vary in different factories. The time of cooking ranges from 20 to 45 minutes.

After the lye has accomplished its work the corn is run through a cylinder which removes the hull and tops. The corn is next washed. Some canners soak the corn over night so that the kernels will swell to the maximum before canning; others soak and cook it for only an hour or two or fill the cans at once, depending upon the swelling in the processing. The soaking has the effect of getting rid of traces of lye and makes a more tender kernel and a clearer liquor. Hominy is usually put up in two grades.

PEAS.

It is highly important that peas be put in the can as soon as possible after they are picked. For this reason a great many packers either grow their own peas or build the cannery as near as practicable to the fields where the peas are grown. When the peas are well grown and still tender, the vines are cut by mowing machines or special pea harvesters, loaded on wagons, and hauled to the factory. They are next put through the vining machine, which separates the peas from the pods. The peas are passed through a fanning mill, which removes the pieces of pods, leaves, and dirt, after which they are washed in wire cylinders known as squirrel cages. The peas are graded for size, either before or after washing. This is usually done by passing them over vibrating screens, with holes of a definite size, or through cylinders with sections having perforations corresponding to those in the screens.

Peas are usually blanched for from 1 to 4 minutes. They are processed at about 235° F. for from 35 to 40 minutes, depending upon their freshness and state of maturity. The canned peas are immediately cooled in order to arrest cooking and insure a clear liquor.

The following standards for canning peas have been adopted by the United States Department of Agriculture and many of the States, upon recommendation of the joint committee on definitions and standards:

Canned peas are the canned vegetables prepared from the well-developed but still tender seeds of the common or garden pea (*Pisum sativum*) by shelling, winnowing, and thorough washing, with or without grading and with or without precooking (blanching), and by the addition, before sterilization, of the necessary amount of potable water, with or without sugar and salt.

Canned pea varieties.—Early peas are peas of early maturing sorts having a smooth skin.

Sugar peas, sweet peas, are peas of later maturing varieties having a wrinkled skin and sweet flavor.

Canned pea grades.—Fancy peas are young, succulent peas of fairly uniform size and color, unless declared to be ungraded for size, with reasonably clear liquor, and free from flavor defects due to imperfect processing.

Standard peas are less succulent peas than the fancy grade, but green and of mellow consistency, of uniform size and color, unless declared to be ungraded for size, with reasonably clear liquor, though not necessarily free from sediment, and reasonably free from flavor defects due to imperfect processing.

Substandard peas are peas that are overmature, though not fully ripened, or that lack in other respects the qualifications for the standard grade.

Canned pea sizes.—No. 1 peas are peas which were, before precooking (blanching), small enough to pass through a screen of $\frac{9}{32}$-inch (7 mm.) mesh.

No. 2 peas are peas which were, before precooking (blanching), small enough to pass through a screen of $\frac{10}{32}$-inch (8 mm.) mesh.

No. 3 peas are peas which were, before precooking (blanching), small enough to pass through a screen of $\frac{11}{32}$-inch (8.7 mm.) mesh.

No. 4 peas are peas which were, before precooking (blanching), small enough to pass through a screen of $\frac{12}{32}$-inch (9.5 mm.) mesh.

No. 5 peas are peas which were, before precooking (blanching), small enough to pass through a screen of $\frac{13}{32}$-inch (10.3 mm.) mesh.

No. 6 peas are peas not all of which were, before precooking (blanching), small enough to pass through a screen of $\frac{13}{32}$-inch (10.3 mm.) mesh.

The inspector should observe the efficiency of the sorting and removal of defective and imperfect peas, the disposal of the vines, and the fill of the cans (page 8). A sample form for reporting a pea-cannery inspection is given on page 18.

PEPPERS.

The pods of peppers are 6 or 7 inches long and from $1\frac{1}{2}$ to 2 inches wide. They are picked green and just before any tinge of red appears. It is necessary to handle them quickly to prevent decomposition, and molding skins are removed from the fleshy portion, either mechanically or by hand, care being taken to leave the pods as nearly whole as possible. In order to loosen the skins, the pods are roasted by being either passed through rotating cylindrical ovens or dipped in boiling oil. Pods are cleaned of most of the seeds, after which they are thoroughly washed in running water, folded, and packed tightly in cans. Some canners spread the pods on trays to dry after washing, then salt and pack them. A liquor containing tomato juice or a weak brine is added, and the cans are capped and processed in boiling water for a period not exceeding 30 minutes.

A small part of the pack is canned for ripe peppers. The pimento or sweet pepper, packed when fully colored, is treated in the same manner, although usually canned in tomato juice.

POTATOES, SWEET.

Sweet potatoes are canned extensively in Delaware and Maryland and in the South. As a general rule, only the smaller tubers are used by the canner. The tubers are placed in baskets or shallow slat boxes and cooked with live steam for about 10 minutes in a suitable inclosure of wood or metal. The hot tubers are taken out and the skin is removed at once, by hand in small plants, or in rotary machines made for the purpose. Those treated in the machines require further hand treatment for the complete removal of bits of skin, roots, etc.

There are two distinct methods of packing sweet potatoes. In one the cans are hand filled completely, the operators using sufficient pressure to mash the soft potatoes and squeeze out all air, the can being completely filled except a slight depression at the top. In the other method, the operators fill the potatoes into the can so that they lie close together but are not mashed, as little space as possible being left as voids. In the first method, the contents turn out as a solid mass, the outline of the individual tubers being lost. In the second method the mass shows the outlines of tubers which can be picked apart and cooked as individual potatoes. The voids or air spaces sometimes give trouble because the potatoes surrounding them are more or less darkened and unsightly, owing to the action of the air. Because of this action of the air, some canners put up a solid pack. Those who pack by the second method give the filled cans a very long, hot exhaust in unusually long exhaust boxes, in this way driving out nearly all of the air, and then seal the hot cans at once, thus securing a finished article which commands a higher price than that packed by the other method. Sweet potatoes require a very long period of processing, especially when packed in No. 10 cans.

PUMPKINS.

Pumpkins, carefully selected for canning, are stemmed and well washed to remove any adhering dirt. They are cut into large pieces, either by knives or roller disks, and are given a general washing in a heavy squirrel cage, the principal object being to remove seed and loose fiber. The fiber is then put in large iron crates and cooked in a retort until it softens, which requires about 20 minutes at 240° F. It is next run through a cyclone which removes the hard part of the skin and the tough fibers. If it is of a good consistency the pulp is cooked very little, but if light or thin it is evaporated until it has the right body. It is filled into the cans while hot, sealed, and processed at 250° F. for 90 minutes. Pumpkins are packed principally in No. 3 cans. In some canneries the seed and pulp are not removed before cooking, as certain packers believe that the seed and fibrous pulp surrounding them produce a better taste.

RHUBARB.

Rhubarb is washed in large tanks of running water and at the same time inspected for any imperfections. It is next cut by means of a series of small saws set an inch apart on a shaft. The rhubarb is laid on a carrier which feeds each stick crosswise to the saws. The cans are then filled and hot water is added to fill the interspaces.

The practice in some canneries is to first strip or peel the stems before they are cut and then heat the rhubarb in a preserve kettle before filling into the can. The cans are processed for about 13 minutes at boiling temperature.

SAUERKRAUT.

Sauerkraut is made by the natural fermentation of cabbage in casks or tanks. For canning it is made in the usual way. The fresher the kraut the better it is for canning. Cans are filled full and weighed, and sufficient hot brine to fill the interspaces is added. The can is then exhausted, capped, and processed at boiling temperature for 25 minutes.

The inspector should give particular attention to the condition of the raw material used in making the kraut, the quality of the kraut, and the fill of the can.

SOUPS.

The great variety of soups canned include beef, bouillon, celery, ox-tail, mock-turtle, chicken, veal, chicken gumbo, consommé, green turtle, clam broth, clam chowder, mutton broth, tomato, tomato okra, vegetable, pea, asparagus, vermicilli, and julienne.

There are no standards for soups; each is made according to the formula of the particular packer. The making of soups is peculiarly a chef's art. All the meat products which go into their composition should be United States Government inspected, as the soups are likely to enter interstate commerce. Soups are classed as meat or vegetable, although there are but few that are not made from some kind of meat stock. The inspector should give particular attention to the kind of meat used.

Fresh vegetables are preferable for making soups, although canned or dried vegetables may prove satisfactory. The vegetables used are prepared separately, washed, peeled, cut into pieces, cubes, or the special forms used by the individual packer, blanched, and in some cases given a separate cooking to secure the proper tenderness. These are mixed in various proportions according to the formula and placed in the cans by weight. The stock is added afterwards. The process depends upon the body, whether thick or thin, and upon the quantity of meat used.

The inspector should give particular attention to the quality of raw material used, the sanitary condition of the factory and equipment, the health of the workers, and the like. Attention should also be given to the label. See that the finished product is labeled in accordance with the products actually put into the can.

SPINACH.

Spinach is canned extensively in California. The canning begins about the middle of March and continues until the last of June, although some is packed also in the fall, between the first of September and the middle of December.

The entire top of the plant is cut off close to the ground, thrown loosely into crates or wagons, and hauled to the cannery. The large stems, the flowering tops, and any discolored or old leaves are separated and discarded by the women operatives. The sorted spinach is then washed thoroughly to free it from sand and adhering dirt, by passing it through a perforated revolving iron drum which rolls it about and sprays it thoroughly with cold water by means of six or more fan sprays running under forced pressure. It is next blanched in boiling water or steam for from 3 to 10 minutes.

Spinach is allowed to drain for a few minutes and then while still hot it is packed in the cans by means of forks or wooden paddles. A salt brine averaging 3 per cent salt is added and the product is exhausted, sealed, and cooked in retorts for varying periods of time according to the size of the can.

The inspector should give particular attention to the net weight of the spinach actually put into the cans exclusive of brine. Sometimes the spinach going into the can is not well drained, in which case the amount of water weighed in as spinach would be large. The sorting and washing process should be carefully observed to ascertain whether all dirt and insects have been properly removed. Careful attention should also be given to the time and temperature of processing and to the methods for controlling them. A number of deaths have been caused by the presence of *Bacillus botulinus* in canned spinach. Thorough sterilization is necessary to prevent the possibility of this danger.

SQUASH.

Squash is canned in the same manner as pumpkin (p. 35), to which it is closely related.

SUCCOTASH.

Succotash is made by mixing green corn and green beans, usually Lima beans. Soaked beans are sometimes used and they should be declared upon the label. In the regular field run of Lima beans,

some will be further advanced than others, while all the pods may be green. In blanching, some of the beans may turn white. On breaking them they may appear mealy and thus when the can is opened, give the product the appearance of being soaked. In fancy succotash these white beans are picked out by hand. The percentage of beans in succotash varies from 20 to 40. The cut corn and blanched beans are mixed, after which they are treated in the same way as corn, being given the same sugar and salt brine, preliminary cooking, and process.

Observe the percentage of beans used, and whether they are green or soaked.

TURNIPS.

After the tops have been removed turnips are delivered to canners in lug boxes, washed in cold water, blanched to facilitate the removal of the outer skin, hand peeled, and quartered. After another washing in cold water they are hand packed, and exhausted for from 5 to 8 minutes at 212° F. The cans are filled with hot brine, capped, and processed in the same manner as beets and carrots. The grades are standards and seconds, with but slight difference between them.

The inspector should give particular attention to the fill of can and to net weight.

OTHER VEGETABLES.

Other vegetables which are canned in relatively small quantities are celery, cucumbers, mushrooms, and okra.

CONCLUSION.

Alertness, vigilance, diplomacy—these are the characteristics of the efficient inspector. No detail bearing on the whole canning process escapes him; no opportunity to secure accurate information from any source is lost. Yet in analyzing his observations he is selective, and in his report he places the emphasis upon the characteristic and vital points. The characteristic points are those which give the cannery under consideration a grade of unsatisfactory, fair, good, or excellent; the vital points are those which, because of the conditions in the cannery, directly affect the quality and wholesomeness of the food in the can.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1085

Washington, D. C. PROFESSIONAL PAPER JULY, 1922

BROAD-NOSED GRAIN WEEVIL.

By Richard T. Cotton,

Scientific Assistant, Stored-Product Insect Investigations, Bureau of Entomology.

CONTENTS.

INTRODUCTION.

The broad-nosed grain weevil, *Caulophilus latinasus* Say, has received but little attention from economic entomologists, and practically nothing has been published on the biology of this insect. It is now widespread over Florida and has been reported from Georgia and South Carolina. It is not unlikely that it will gradually spread to other parts of the South and add to the already heavy damage caused by the rice weevil, *Sitophilus oryza* Linn.

The damage caused by the broad-nosed grain weevil is more than has been generally supposed. While more often found infesting stored corn and chick peas, it commonly attacks a variety of seeds and cereals. Infested seeds are quickly reduced to a powdery mass by the combined efforts of the grubs and adult weevils.

It is interesting to note that whole grain or seed of a medium degree of hardness is entirely immune from the attack of this weevil. The writer has many times confined weevils with whole grain and chick peas, with the result that invariably the weevils died from starvation without being able to penetrate the grain.

The broad-nosed grain weevil, however, is often associated with the common rice weevil, *Sitophilus oryza*, and the attack of the common rice weevil makes it a simple matter for its weaker associate to reach the softer portions of the grain. Cracked, damaged, or soft seed is quickly infested by the broad-nosed grain weevil.

The following notes on the life history and habits of this weevil were made at Orlando, Fla., during 1919, 1920, and a part of 1921.

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ORIGIN AND ECONOMIC HISTORY.

Caulophilus latinasus was described in the year 1831 by Thomas Say (*13: 1831, p. 30; 1859, p. 299*)[1] from specimens taken in Florida. It is thought to be native to the American continent and is not as yet very widely distributed.

In 1878 Schwarz (*14, p. 468*) recorded it from Florida as "rare, beaten from dead twigs." Ten years later Riley and Howard (*11, p. 198*) stated that the genus lived under the bark of dead and decaying wood or bored into decaying wood of deciduous or coniferous trees. In 1894 Townsend[2] reported it as occurring in a can of ginger. Two years later Chittenden (*3, p. 29–30*) reported it for the first time as attacking stored grain, having found it in a shipment of corn and chick peas obtained from the Mexican exhibit at the Atlanta Exposition. In 1897 (*4, p. 30–31*) and 1911 (*5*) Chittenden published short accounts concerning the occurrence of this weevil in the United States, its synonymy, its reported distribution, the damage caused by it, etc., and also included a list of references to this species in literature.

Since then it has been reported by the following writers as attacking seeds of the avocado in Florida: Schwarz (*1, p. 183*), Sasscer (*12, p. 4–5*), Blatchley and Leng (*2, p. 535*), Pierce (*8, p. 30, pl. 49*), Popenoe (*9, p. 6*) (*10, p. 34–35, pl. 40*), Hoyt (*6*), and Moznette (*7*). It was also found by inspectors of the Federal Horticultural Board infesting roots of dasheen in storage at Brooksville, Fla.

PRESENT KNOWN DISTRIBUTION.

Caulophilus latinasus is now widespread over Florida and has been reported from South Carolina and Georgia. So far as can be determined, it has not become permanently established in either of the two latter States. It is abundant within a few miles of the boundary between Florida and Georgia, however, and may be expected to invade the southern portion of Georgia.

It is known to occur in Jamaica, Cuba, Porto Rico, Mexico, Guatemala, and Madeira, and is doubtless common throughout the islands of the West Indies and in the countries of Central and South America.

FOOD.

Caulophilus latinasus is known to breed in corn, chick peas, millets, acorns, and seed of the avocado and has occasionally been found breeding in the roots of the dasheen and in sweet potatoes.

In addition, the adult weevils feed readily on wheat, barley, wheat flour, ginger, and macaroni. The writer has occasionally found them feeding on fresh fruits, and E. R. Sasscer, of the Federal Horticultural Board, states that the board has observed injury to chayotes by this weevil.

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[1] Reference is made by number (italic) to "Literature cited," p. 10.

[2] TOWNSEND, C. H. T. Institute of Jamaica, Notes from the Museum, No. 78, 1894. (Hectographed.)

LIFE HISTORY (Pl. I).[3]

The adults of the broad-nosed grain weevil possess functional wings, and although not great fliers they are capable of making short flights in search of food. They fly to the cornfields in the summer, feed on the grain, and deposit eggs in it before it becomes fully hardened.

The damaged and exposed ears of corn are the ones that are attacked by the weevils, those ears that have a well-developed and tightly fitting shuck being entirely immune from attack.

After the grain is harvested and placed in storage the work of destruction continues. The kernels infested in the field are completely destroyed, and the multiplying weevils attack cracked and broken kernels and grain that is softened by excess moisture or is damaged by the depredations of other grain pests.

OVIPOSITION.

Under favorable conditions oviposition occurs more frequently during the hours of the morning; eggs are laid, however, at all times of the day.

The female weevil excavates the egg cavity in a manner very similar to that of *Sitophilus oryza*. The weevil places herself in the desired position. The sharp hook or claw on the end of the tibia of each leg is dug into the surface of the kernel, the four legs thus forming pivots on which the body oscillates. This oscillating movement of the body, together with a turning movement of the head, imparts to the proboscis a combined up-and-down and rotary motion. The position of the legs is not changed, as a rule, until the excavation is completed, and the proboscis or beak is seldom withdrawn during this time. Work on the cavity continues until its depth approximates the length of the beak from the tip to the eyes. The sides are then smoothed off.

After the completion of the cavity the weevil reverses her position and places the tip of her abdomen over the mouth of the egg cavity. After a period of from two to three minutes the egg is ejected from the ovipositor into the cavity, followed by a liquid secretion that forms a cap and cements the egg into place. This secretion quickly hardens. Immediately after the egg is deposited the weevil turns about and tamps down the edges of the egg cap with her beak, picking up small pieces of the borings from the excavation and tamping in around the edges.

The egg cap is transparent, and the outer surface is invariably exactly level with the surrounding surface of the corn. After the young larva has emerged from the egg and the egg cavity is filled with larval borings it is often difficult to detect the original position of the egg.

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[3] In breeding experiments from which the life-history data were taken corn was used as the host seed.

WHERE THE EGGS ARE LAID.

In broken or damaged corn the eggs usually are laid either in the germ or in the soft starch of the endosperm, and very rarely in the harder horny part of the kernels. In the case of undamaged kernels eggs are laid only if the corn is very soft, as ordinarily the seed coat is too tough for the weevil to penetrate.

OVIPOSITION PERIOD AND NUMBER OF EGGS LAID.

The preoviposition period of the broad-nosed grain weevil is apparently a little longer than that of the other grain weevils. The shortest period observed was nine days; however, it was not uncommon for a period of from one to two months to elapse after emergence before the first egg was laid.

The oviposition period, once started, extends over most of the remainder of the life of the weevil. The longest oviposition period observed was 176 days; the average was somewhat less, approximately 123 days.

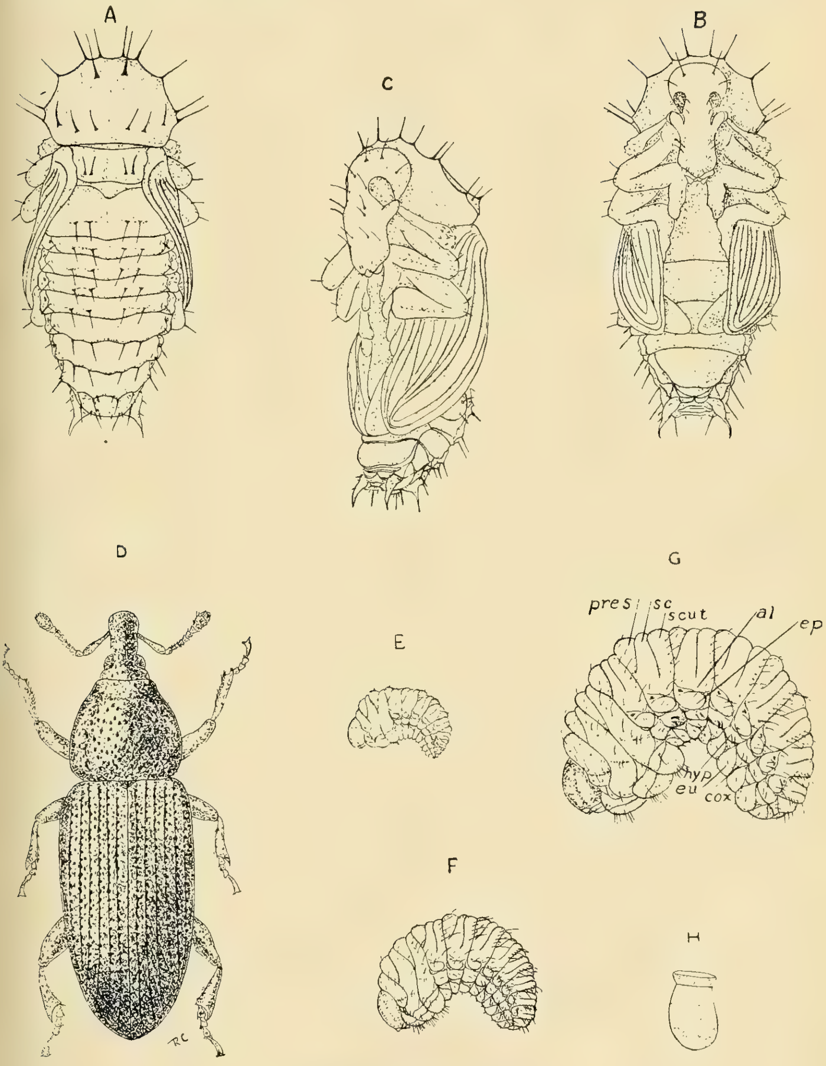
The number of eggs laid by the female of this species is not exceptionally great. The largest number laid by a single female under observation was 229. These were laid over a period of 124 days—August 13, 1919, to December 14, 1919, an average of almost 2 a day. As shown in Table 1, the average number laid is about 136. Table 1 contains data concerning the preoviposition period, the oviposition period, the number of eggs laid, and the length of life of 11 representative individual weevils.

TABLE 1.—*Oviposition data for Caulophilus latinasus.*

Weevil No.	Date weevil emerged.	Length of preoviposition period.	Date first egg was laid.	Date last egg was laid.	Length of oviposition period.	Number of eggs laid.	Date of death.	Length of life.
		Days.			*Days.*			*Days.*
1	June 28, 1919	16	July 14, 1919	Dec. 15, 1919	155	196	Dec. 20, 1919	176
2	do	46	Aug. 13, 1919	Dec. 14, 1919	124	229	Dec. 22, 1919	178
3	Sept. 11, 1919	13	Sept. 24, 1919	Dec. 15, 1919	83	152	do	103
4	Feb. 25, 1920	31	Mar. 27, 1920	Aug. 4, 1920	131	65	Aug. 13, 1920	171
5	May 6, 1920	57	July 2, 1920	Oct. 6, 1920	97	156	Oct. 17, 1920	165
6	Aug. 1, 1920	9	Aug. 10, 1920	Jan. 24, 1921	168	182	Feb. 1, 1921	185
7	do	9	do	Oct. 27, 1920	79	85	Nov. 4, 1920	96
8	Aug. 7, 1920	12	Aug. 19, 1920	Oct. 26, 1920	69	68	Nov. 2, 1920	88
9	do	13	Aug. 20, 1920	Feb. 11, 1921	176	160	Feb. 16, 1921	194
10	Aug. 9, 1920	22	Aug. 31, 1920	Feb. 9, 1921	163	127	do	192
11	Oct. 12, 1920	12	Oct. 24, 1920	Feb. 11, 1921	111	75	Feb. 19, 1921	131
Average		22			123	136		152

RATE OF OVIPOSITION.

Oviposition continues throughout the year in a fairly uniform manner. In the summer months the rate of oviposition averages about two eggs a day, while in winter the rate drops to about one per day. It is not uncommon for three and four eggs to be laid per day during the summer, and in the colder portions of winter oviposition may cease entirely for a day or two. The greatest number laid by one individual in 24 hours was six. This occurred but once. Table 2 contains data concerning the rate of oviposition at various times of the year.



CAULOPHILUS LATINASUS.

A, Pupa, dorsal view; B, pupa, ventral view; C, pupa, lateral view; D, adult; E, first-stage larva; F, second-stage larva; G, mature larva; H, egg.
Key to larval parts: *al*, Alar area; *cox*, coxal lobe; *ep*, epipleurum; *eu*, eusternum; *hyp*, hypopleurum; *pres*, praescutum; *sc*, scutum; *scut*, scutellum.

TABLE 2.—*Rate of oviposition of Caulophilus latinasus.*[1]

Date.	Temperature.			Number of eggs laid by weevil No.—						
	Max.	Min.	Mean.	1	2	3	4	5	6	7
1920.	° F.	° F.	° F.							
Aug. 10	94	70	82	1	1	...	...	...	...	...
12	95	70	82.5	1	0	[2]	...	...	...	...
19	95	69	82	2	1	1	[2]	...	...	...
20	95	69	82	2	1	1	1	...	...	..
26	97	70	83.5	1	1	4	1	...	...	..
27	94	69	81.5	1	2	3	1	...	...	..
Sept. 4	90	69	79.5	1	2	1	1	[3]	...	...
5	92	70	81	2	2	2	2	1	...	...
11	96	72	84	4	1	0	2	1	...	...
12	98	69	83.5	2	2	2	1	2	...	...
17	89	67	78	2	1	1	1	1	...	...
18	92	68	80	3	3	1	1	2	...	...
24	84	70	77	4	2	1	2	0	...	...
25	89	70	79.5	4	2	1	2	2	...	...
Oct. 1	75	46	60.5	2	1	1	1	1	...	...
2	82	48	65	1	2	0	1	0	...	...
8	80	50	65	0	0	1	0	0	...	...
9	84	52	68	0	0	1	0	0	...	...
15	88	62	75	0	0	1	0	0	...	...
16	88	60	74	0	0	1	0	0	[4]	[4]
26	87	64	75.5	2	2	1	2	1	1	1
27	88	66	77	2	2	[5]	2	2	1	1
Nov. 1	84	59	71.5	1	[6]	...	1	0	0	0
2	86	57	71.5	2	...	...	2	0	0	0
7	85	60	72.5	1	...	...	2	0	0	1
8	86	60	73	2	...	...	2	0	0	1
14	78	57	67.5	0	...	...	1	2	0	1
15	75	63	53.5	0	...	...	0	0	0	0
20	81	52	66.5	1	...	...	1	2	0	0
21	83	54	68.5	0	...	...	1	2	1	1
28	76	58	67	0	...	...	1	2	1	1

Date.	Temperature.			Number of eggs laid by weevil No.—						
	Max.	Min.	Mean.	1	2	3	4	5	6	7
1920.	° F.	° F.	° F.							
Nov. 29	77	48	62.5	1	...	...	1	1	1	1
Dec. 1	71	58	64.5	1	...	...	3	1	1	1
2	70	41	55.5	0	...	...	0	0	1	0
7	78	59	68.5	1	...	...	2	2	1	1
8	72	58	65	2	...	...	2	2	1	2
13	84	55	69.5	3	...	...	1	3	2	1
14	75	67	71	2	...	...	1	2	2	0
18	70	36	53	0	...	...	0	0	0	0
19	75	37	56	0	...	...	0	0	0	0
26	78	44	61	1	...	...	1	1	1	1
27	84	68	76	1	...	...	1	3	4	2
1921.										
Jan. 1	84	44	64	1	...	...	1	2	2	2
2	79	62	70.5	1	...	...	2	2	1	1
7	74	45	59.5	1	...	...	0	1	0	1
8	79	51	65	0	...	...	0	0	1	0
13	78	48	63	1	...	...	1	1	1	0
14	79	61	70	0	...	...	0	1	1	1
18	79	46	62.5	0	...	...	2	1	0	1
19	73	53	63	1	...	...	0	1	0	1
23	83	50	66.5	1	...	...	1	1	1	1
24	81	49	65	1	...	...	0	1	1	1
Feb. 1	84	50	67	[7]	...	...	0	1	0	0
2	82	44	63	...	...	...	0	0	0	1
7	84	58	71	...	...	...	1	2	1	1
8	84	52	68	...	...	...	1	2	1	2
13	74	38	56	...	...	...	0	0	0	1
14	74	40	57	...	...	...	0	0	0	0
20	.....	.....	.....	...	...	...	[8]	[8]	[9]	2
21	80	52	66	...	...	...	...	...	...	1
	.....	.....	.....	...	...	...	...	...	...	[10]

[1] The mean temperature of the crib in which these records were made is about 3° to 4° F. higher than the outdoor temperature quoted in this table.

[2] Emerged Aug. 7, 1920.
[3] Emerged Aug. 9, 1920.
[4] Emerged Oct. 12, 1920.
[5] Died Nov. 2, 1920.
[6] Died Nov. 4, 1920.
[7] Died Feb. 1, 1920.
[8] Died Feb. 16, 1921.
[9] Died Feb. 19, 1921.
[10] Still alive.

EGG STAGE.

During the summer months, with the temperature ranging from 65° to 99° F., with a mean of 81°, the egg hatches in four days. As the weather gets colder the incubation period gradually lengthens until, in the coldest winter months, with the temperature ranging from 34° to 88° F., with a mean of 62°, from 10 to 14 days is the normal length of the period.

LARVAL PERIOD.

When the egg is placed in the germ or in the starch of the kernel the young grub, breaking through the bottom of the shell, finds a plentiful supply of food. Development of the grub is most rapid when it is located in the germ. Progress is a little slower in the seft starch, while development in the tough horny endosperm is very slow and the larval period is greatly prolonged.

NUMBER OF LARVAL STAGES.

There are three larval stages. The first two are about equal in length, while the third is slightly longer. Table 3 gives data showing the variation in the length of these stages at different times of the year.

TABLE 3.—*Life history data of Caulophilus latinasus.*

No.	Date egg was laid.	Date egg was hatched.	Length of egg stage.	Date of first molt.	Length of first larval stage.	Date of second molt.	Length of second larval stage.	Prepupal form.	Length of third larval stage.	Date pupated.	Length of pre-pupal stage.	Adult emerged.	Length of pupal stage.	Period from egg to adult.	Temperature for period of development. Maximum.	Minimum.	Mean.
			Days.		*Days.*		*Days.*		*Days.*		*Days.*		*Days.*	*Days.*	° *F.*	° *F.*	° *F.*
1	Aug. 1	Aug. 5	4	Aug. 11	6	Aug. 17	6	Aug. 22	5	Aug. 23	1	Aug. 28	5	27	94	71	82.5
2	8	12	4	18	6	22	4	30	8	31	1	Sept. 5	5	28	94	69	81.5
3	10	14	4	19	5	22	3	29	7	30	1	4	5	25	94	69	81.5
4	11	15	4	20	5	26	6	Sept. 1	6	Sept. 2	1	7	5	27	94	69	81.5
5	13	17	4	22	5	27	5	1	5	2	1	7	5	25	94	69	81.5
6	Mar. 25	Mar. 30	5	Apr. 7	8	Apr. 13	6	Apr. 26	13	Apr. 27	1	May 2	5	38	86	61	73.5
7	28	Apr. 2	5	10	8	17	7	27	10	28	1	4	6	37	86	61	73.5
8	June 30	July 6	6	July 12	6	July 17	5	July 31	14	Aug. 1	1	Aug. 6	5	37	92.5	70	81
9	July 1	5	4	12	7	17	5	23	6	July 24	1	July 29	5	28	93	70	81.5
10	1	5	4	12	7	16	4	27	11	28	1	Aug. 2	5	32	93	70	81.5
11	10	14	4	0	6	25	5	Aug. 8	14	Aug. 9	1	14	5	35	92	70	81
12	11	15	4	1	6	26	5	3	8	4	1	9	5	29	92	70	81
13	Nov. 11	Nov. 18	7	Dec. 2	14	Dec. 19	17	Dec. 30	11	Jan. 1	2	Jan. 14	13	64	76	51	63.5
14	16	24	8	5	11	20	15	Jan. 5	16	7	2	20	13	65	76	49	62.5
15	22	Dec. 2	10	12	10	27	15	11	15	13	2	Feb. 9	27	79	76	50	63
16	Dec. 6	20	14	Jan. 3	14	Jan. 13	10	Feb. 3	21	Feb. 5	2	20	15	76	76	50.5	63
17	13	27	14	10	14	26	16	14	19	15	1	26	11	75	75	50	62.5
18	22	Jan. 2	11	14	12	27	13	11	15	12	1	24	12	64	76	51	63.5
19	Jan. 4	14	10	27	13	Feb. 8	12	22	14	24	2	Mar. 8	12	63	76	51	63.5

LARVAL HABITS.

The larva or grub bores straight down into the grain at first and is rarely found near the surface. It tunnels around rather aimlessly, filling up the passageway behind it with frass and borings. It usually remains in the soft parts of the grain.

PREPUPAL STAGE.

When fully grown the larva prepares for the change to the pupa or resting stage. It uses the end of its burrow for a pupal chamber, packing the frass and borings at the ends into a compact mass.

The larva lengthens out and becomes sluggish, assuming the prepupal form. This stage lasts for one day in warm weather and two days in winter.

PUPAL STAGE.

The pupal stage lasts for a period of five days during warm weather when the temperature ranges from 65° to 99° F., with a mean of about 81°. As with the other stages, cold weather has the effect of lengthening the period. Table 3 contains data showing the varying length of this stage at different times of the year.

NUMBER OF MALES AND FEMALES.

Of several hundred weevils reared in the laboratory and of large numbers collected in the field, the males and females were about equal in numbers. The males and females closely resemble each other in outward appearance and can not be differentiated without the aid of a magnifying glass.

As with many other weevils the beak of the female differs slightly from that of the male and affords a ready means of distinguishing between the two sexes. The beak or proboscis of the female is approximately equal in width for its entire length and is longer and more slender than that of the male. The beak of the male is slightly enlarged at the tip and narrows gradually toward the base.

COPULATION.

Copulation occurs within a few days after emergence and is repeated at intervals. It occurs chiefly at night. These weevils are rarely to be seen in copula during the day.

Unfertilized females have been observed to lay eggs but rarely. None of these eggs have been found to hatch, so it is doubtful whether unfertilized females are capable of laying fertile eggs.

LIFE CYCLE.

The period from egg to adult during warm weather averages about 30 days, which with an average preoviposition period of 22 days gives

an average life cycle of 52 days. This is 18 days longer than the shortest record obtained and considerably shorter than the life cycle during the winter months.

LONGEVITY.

The average length of life of the adult weevil is about 152 days when reared in captivity. Of fertilized females one lived for 209 days while two unfertilized females lived for 240 and 244 days, respectively.

When deprived of food these weevils are capable of living for extended periods if the temperature is not too high. Fifty weevils were placed without food in a chamber with a constant temperature of 60° F. The majority lived for a period of 55 days, while a few survived for 90 days and one for 96 days. During normally warm weather these weevils will live for from 5 to 12 days without food.

PARASITES.

The larvæ of this weevil are attacked by three hymenopterous parasites, *Cercocephala elegans* Westwood, *Aplastomorpha vandinei* Tucker, and *Zatropis* sp.

Larvæ, pupæ, and eggs are all attacked by a predacious mite, *Pediculoides ventricosus* Newport.

CONTROL MEASURES.

This weevil may be effectively controlled by the standard remedies advocated for the control of insect pests of stored grain.

TECHNICAL DESCRIPTION OF IMMATURE STAGES.

EGG.

Egg opaque, shiny white, bottom broadly rounded, top flattened and fitting into a translucent cap. Length, without cap, 0.45 to 0.47 mm.; width, 0.27 to 0.32 mm.

LARVA.

Mature larva 2 to 2.5 mm. in length, a white, footless, fleshy grub, with body curved and wrinkled. Head light brown or straw color, the anterior margin and mandibles a darker brown. Head about as broad as long, almost circular in form. Epicranial and frontal sutures distinct and light in color. There are also two oblique, longitudinal, light stripes rising from the frontal sutures and coalescing with the epicranial suture near the base of the head. Frons subtriangular, with a distinct dark median line running from posterior angle to middle, and indicating carina. Frons provided with four pairs of large setæ, sutural margins each bearing one seta. Epicranial lobes bearing the following setæ: One close to posterior angle of frons and located in the oblique, longitudinal stripe rising from the frontal suture, one small seta posterior to this and near occiput, two anterior to it on disk of epicranium, two opposite middle of frons, one opposite middle of mandible, one opposite hypostomal angle of mandible and one on hypostoma near base of mandible. Epistoma represented by thickened anterior margin of the front. Pleurostoma represented by somewhat darker declivous

area surrounding the mandibular foramen. Mandibles stout, triangular, with the apex produced into an acute apical tooth. Inner edge toward apex provided with a subapical tooth and a small medial tooth, no molar structure. Dorsal area of each mandible armed with a pair of stout bristles set close together. Eye represented by a well-defined black spot beneath the exoskeleton. Clypeus broad at base, sides narrowing towards apical angles; distinctly broader but not as long as labrum. Epistomal margin provided with two fine hairs on each side. Labrum about as broad as long, rounded in front, provided with three pairs of large setæ and five pairs of short, thickened, marginal setæ.

Maxillæ terminated by a 2-jointed palpus and setose maxillary lobe. Maxillæ each provided with four setæ as follows: One on first segment of palpus, two on vaginant membrane between palpus and palpifer, and one stouter and larger midway between palpus and cardo. The stipes labii enforced posteriorly by a median triangular chitinization bear 2-jointed palpi and a single pair of setæ. Ligula bearing four small setæ. Mentum and submentum fused and bearing three large setæ on each side. Pronotum simple and undivided. Præscutal and scuto-scutellar areas roughly indicated by rows of setæ. Mesothoracic and metathoracic segments divided above into two areas representing præscutum and scuto-scutellum; below and adjacent to epipleurum is the alar area. Below ventro-lateral suture are a well-defined hypopleurum, coxal lobe, and eusternum. The thoracic spiracle, located on the pre-epipleural lobe of the mesothorax, is bifore, with the fingerlike air tubes pointing dorsad, and is somewhat larger than the abdominal spiracles. Ten abdominal segments, ninth small, tenth reduced. Each tergum of first eight abdominal segments divided above into three distinct areas—praescutum, scutum, and scutellum. Below and adjacent to epipleurum is the alar area. Below ventro-lateral suture are a well-defined hypopleurum, coxal lobe, and eusternum. Abdominal segments provided with setæ as follows: Two on præscutum, five on scutellum, two on alar area, two on epipleurum, one on coxal lobe, and two on eusternum. Each of the first eight abdominal segments bears a bifore spiracle, that of the eighth being slightly larger than the rest.

Stage.	Width of larval head.
1	0.22 to 0.23 mm.
2	.33 to .38 mm.
3	.53 to .57 mm.

PUPA.

Pupa white when first transformed. Length, 2.8 to 3 mm.; width, about 1.3 mm. Tips of elytra attaining the sixth abdominal segment, tips of metathoracic tarsi not extending beyond wing tips. Head rounded, beak short and broad. Head provided with two prominent spines toward the vertex, two smaller ones on sides above eyes, a spine on each side of front between eyes, two pairs on beak between frontal ones and base of antennæ, two pairs on beak between base of antennæ and tip of beak, and four pairs of small setæ on tip of beak. Prothorax provided with two pairs of antero-marginal setigerous tubercles, one pair of antero-lateral, two pairs of postero-lateral, and four pairs of dorsal setigerous tubercles. Mesonotum and metanotum each provided with two pairs of spines. Abdomen with eight distinct dorsal tergites; dorsal area of each armed with two pairs of large spines; lateral area of each tergite armed with a spine at base of which is a small seta. Epipleural lobes each obscurely armed with one or two minute setæ. Ninth segment armed as usual with two prominent pleural spines.

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SHRINKAGE OF SOFT PORK UNDER COMMERCIAL CONDITIONS.[1]

By L. B. Burk, *Investigator in Marketing Live Stock and Meats, Live Stock, Meats, and Wool Division, Bureau of Agricultural Economics.*

CONTENTS.

During the past 10 years the swine industry of the South has developed very rapidly. With this development has come an increased production of soft and oily pork. Until comparatively recent years it was thought that acorns (or mast) was the principal feed that caused soft or oily meat, but when the southern farmers began growing peanuts in large quantities for feed and harvesting them by hogging them down, there was a rapid increase in the number of southern hogs that yielded soft or oily pork. This kind of pork increased enormously, because peanut-fed hogs made profitable gains and the peanut crop could be thus harvested without material labor cost or waste. The crop diversification that followed the extremely low price for cotton at the beginning of the World War caused the southern farmers to adopt more largely the peanut and hog combination. This was found to be so profitable that peanut

[1] This report is the result of a study undertaken by the Bureau of Markets in 1919 for the purpose of ascertaining the causes for differences in the market prices of firm, soft, and oily hogs. Since this work was begun, special appropriations have been made available to the Bureau of Animal Industry for the study of the soft pork problem, which will make possible a much more comprehensive study of the causes of soft pork and their prevention.

Mention should be made of the valuable assistance rendered by Mr. E. V. Baker at Fort Worth, Tex., and by Mr. E. K. Hess at East St. Louis, Ill., in conducting these tests at the packing plants; also by Mr. Clarence T. Marsh, laboratory inspector in charge, St. Louis, Mo., who made the melting-point and iodine-number determinations.

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acreage and hog production increased rapidly, thus constantly increasing the supply of soft and oily pork.

This kind of pork has not been a satisfactory product from the standpoint of the packer or retailer, and this fact has been one of the most disturbing elements in the southern live-stock markets for several years, because of the price penalties imposed on hogs that are alleged to be soft or oily. The development and importance of the hog industry in the South may be realized by comparing the figures of the Department of Agriculture, which show that about 20,000,000 hogs were on farms in the Southern States January 1, 1921, with the slaughter records of some of the southern packing plants, which show that 30 to 50 per cent of the total number of hogs killed during heavy marketing seasons are soft and oily.

Oily pork differs from firm pork in that it remains soft and flabby when chilled. The fat has a yellowish tinge and a glossy appearance. The pork known as "soft" resembles a blending of the characteristics of both the firm and oily. It is whiter than the oily and not so glossy or flabby. It is also much softer than firm meat. Soft or oily meat is more difficult to handle than firm meat and is unattractive in appearance, especially to those accustomed to white, firm meat.

Packers object to handling hogs which produce such pork except at heavy discounts, claiming that the product is more difficult to sell and that it shrinks more than firm pork.

CAUSES OF SOFT AND OILY PORK.

All of the factors that cause soft and oily pork have probably not been discovered, but most of the scientific investigators who have made careful studies of the problem are unanimous in their opinion that feed is the principal factor. It has been demonstrated by careful experiments that hogs fattened almost exclusively on corn or feed of a similar composition chill firm, while hogs fattened exclusively on peanuts invariably chill soft or oily. The increased numbers of peanut-fattened hogs, together with the objectionable features in their products, resulted in a reduction in their market prices that was alleged to be discriminatory. This created much dissatisfaction among southern swine producers, who protested vigorously against such practices.

Before the hog is slaughtered it is impossible to determine the kind of carcass or meat product it will produce, and many shippers fail to understand how live hogs that to all outward appearances are alike in finish, size, and quality should be so radically different after slaughtering and chilling. Admitting a possible difference in the condition of the flesh caused by feed, they can not believe it should justify a price discrimination varying from 2 to 7 cents a pound live weight from that paid for firm hogs. The situation, especially during

and since the war, became so serious that appeals were made to various branches of the Government, particularly the U. S. Department of Agriculture and the Federal Trade Commission, to determine the justice of the penalizing market practices.[2] In response to this demand the Federal Bureau of Markets began an investigation of the problem early in 1919.

Some of the leading live-stock markets where southern hogs are shipped in large numbers were visited, and the following differences in prices per 100 pounds live weight were found to exist between hogs suspected of being soft or oily and those expected to produce firm carcasses.

Place.	Difference.	Place.	Difference.
Fort Worth, Tex...	$2.	East St. Louis, Ill..	$5 to $7.
Birmingham, Ala..	$3 for oily and $1.50 for soft.	Indianapolis, Ind..	$2.
Richmond, Va.....	$3 for oily and $2 for soft.	Kansas City, Mo...	$4.

In view of the fact that there seemed to be no uniformity in the discounts or methods of applying them at any one market, and that great variations prevailed among the different markets, it was deemed advisable to conduct tests which might assist in determining the reason of the discrimination and, if possible, to determine what differences really existed between the three kinds of pork, especially with reference to the shrinkage and merchandising factors. These two factors, therefore, were given careful study and two series of commercial tests were made to ascertain whether the objections cited were material and serious enough to justify the discounts given. The results of the tests and information obtained are described in this bulletin.

Since this work was completed, the Bureau of Animal Industry of the United States Department of Agriculture, in cooperation with a number of State agricultural experiment stations, has undertaken a comprehensive investigation of the soft-pork problem. This line of research is being conducted to determine primarily the various fundamental causes of soft pork and their relationships, and to develop methods of avoiding or overcoming the soft condition. Related questions, including the shrinkage of pork from hogs of the various degrees of firmness through the packing-house processes are being studied in connection with this work. On account of the comprehensive and detailed character of these investigations it will be some time before results can be published.

TESTS ON A COMMERCIAL SCALE.

It was desired to conduct the tests here reported under conditions that would, as nearly as possible, represent the difficulties experi-

[2] The prices fixed for hogs by the Food Administration did not include those suspected of being soft or oily.

enced by the packers in commercial trade, and to use, so far as possible, their methods in curing, handling, and marketing the product.

On account of the lack of adequate facilities and sufficient funds to conduct the tests independently with a quantity of meat large enough to be representative of the packers' volume, the tests were conducted in one of the large packing plants at Fort Worth and in another at East St. Louis. The two packing companies provided the hogs, which were selected by the representatives of the Bureau of Markets assigned to conduct the tests. The companies also provided all of the necessary help and facilities, and in every way cooperated to the fullest extent. The work at each plant was under the direct supervision of a representative of the Bureau of Markets who was familiar with packing-house conditions and who had had several years' experience in conducting tests of a similar nature. The tests were begun in February and completed in June, 1919.

PLAN OF EXPERIMENT.

A series of 8 tests, in which the carcasses of 600 hogs were utilized, was conducted at Fort Worth, Tex., and a series of 4 tests with 200 hogs was carried on at East St. Louis, Ill.

In making the killing tests at Fort Worth, 24 lots of 25 hogs each were used. There were 8 lots each of the oily, soft, and firm classes. These tests were conducted in series, using 75 hogs for each test at Fort Worth and 50 at East St. Louis. At Fort Worth they were divided into lots of 25 in each of the 3 classes. Lots 1, 2, 3 represent one test and 4, 5, 6 another. The 3 lots in each test were taken through all curing processes and the retaining period at the same time. They were handled under identical conditions, and all tests were conducted alike.

The hogs were bought on the open market, divided, marked, and closely followed through every process of slaughter, curing, and retaining by a bureau representative. Those bought at Fort Worth averaged approximately 175 pounds in weight, while those purchased at East St. Louis were slightly heavier. The lots classed as oily at Fort Worth, however, were omitted in the East St. Louis tests because the cooler experts at that market made no distinction between soft and oily carcasses.

The hogs were selected according to weight, quality, and finish, and care was taken to get them as nearly alike as possible. Care also was used in selecting hogs to see that they came from territory which would as nearly as possible insure their chilling either firm or oily as desired, because there was no known method of determining before it was slaughtered how a live hog would chill out. This was demonstrated several times in these tests and may be seen by a comparison of the live-weight and chill-room records of Tables

1 and 2 of the Appendix. It has been claimed by a few men that hogs whose carcasses would chill out oily or firm could be distinguished when alive, but other tests, as well as those reported in this bulletin, show that it can not be done. At some of the markets, especially in the South, hogs with split, cropped, or deeply notched ears and showing traces of "razorback" characteristics often sell at a discount because the buyers are afraid the carcasses of such hogs will be oily. Such suspicion has sometimes caused those who had fattened their hogs on corn to receive an unwarranted discount. Discrimination of this nature has been one of the causes of general dissatisfaction because the extra expense of making the flesh firm by feeding corn was not justified from the feeder's viewpoint.

In some lots in these tests every hog chilled out as selected, but in others hogs bought as oily chilled firm or soft. It was to be expected, therefore, that some of the lots would contain more than one grade of carcass and for that reason conclusions can not be drawn regarding the shrinkage of such lots in the chill room. The results of the live-weight and chill-room test records are found in Tables 1 and 2 of the Appendix.

The test lots were carefully marked and kept separate from the time they were weighed over the stockyards scales until the end of the retaining period. The latter was 19 days at Fort Worth and 21 days at East St. Louis after the meat was taken out of smoke.

The following weights were taken on each lot:

Live weight.		After being cut and trimmed.
Warm dressed weight.		After pumping.
Chilled dressed weight.		Out of cure.
	Wholesale cuts	Out of smoke 6 hours.
		Out of smoke 24 hours.
		Out of smoke 6 days.
		Out of smoke 11 days.
		Out of smoke 19 and 21 days.

From these records the gain or loss in weight from each process, together with the total loss, was determined.

METHODS OF HANDLING THE MEAT.

After the carcasses had remained in the cooler temperature for 36 to 44 hours they were examined and classified by the cooler experts of the packing companies as oily, soft, or firm, according to the degree of firmness. The classifications thus made were checked by the representative of the Bureau of Markets.

In cases where the live hogs selected as being firm or oily did not chill out as expected when bought, other carcasses of hogs of the same size and killed the same day which did represent the kind desired, were substituted for the undesirable ones. Each test therefore consisted of 25 carcasses which were uniformly firm, oily, etc.

After the carcasses had been thoroughly chilled and classified they were transferred to the cutting room, where they were cut into the various wholesale cuts. The primal parts used in the tests consisted of regular hams, skinned hams, shoulders, and sides (bellies). Each group was cured and handled separately, but the oily, soft, and firm meat of each test was taken through the various processes at the same time and cured and handled in the same manner.

The various cuts used were placed in hand trucks of known weight, weighed, taken to the pumping table, where they were pumped with a curing solution, returned to another weighed truck, and the meat and truck weighed again. The gain in weight resulting from the pumping process was thus obtained. After the meat had been pumped and weighed it was placed in vats containing a curing solution of equal strength and similar composition and allowed to remain from 30 to 60 days, depending upon the size of the cut. For example, hams remained in the curing solution from 55 to 60 days, while small bellies (bacon) and picnics (shoulders) remained in cure only 30 days. During the curing process the meat was overhauled several times, and each time the weights were taken by the man in charge of the tests. At the close of the curing period the meat was taken from the vats, put into weighed trucks, allowed to drain, and then hung on weighed iron racks (called trees) ready to be smoked. The empty trucks were again weighed in order to obtain the weight of drained meat out of cure and the initial weight of meat in smoke.

The meat was smoked from 19 to 35 hours, depending upon the size of the cut and the customs of the packing plant in which it was smoked. Weights were again taken 6 hours after the meat was taken out of smoke. The weight was used in calculating the loss in smoke. The meat was then allowed to remain on the trees in the room adjoining the smoke room, where the temperature was about 80° F. During this retaining period the meat was weighed after 24 hours and at the end of 6, 11, and 19 days in the Fort Worth tests, and at the end of 6, 12, and 21 days in the East St. Louis tests.

The meat was retained 19 days at Fort Worth and 21 days at East St. Louis, after being smoked, in order to determine the shrinkage that occurs following this process. The packers usually do not hold meat longer than 5 days after it is taken out of smoke. However, it passes through branch, wholesale, and retail houses before it reaches the consumer. This requires some time and shrinkage continues until it is consumed. It was desired, therefore, to hold the meat in these tests for a period approximating the time usually required for it to pass through the wholesale house and retail stores to the consumer. It is believed, therefore, that the shrinkage shown herewith represents practically all the loss incurred on such cuts by those handling the hogs and the resultant meat from the stockyards to the consumer.

Of the 800 hogs used in the tests, the live and dressed weights of 750 of them are shown in the tables included in this bulletin. The carcasses of 50 hogs used in test No. 4 at East St. Louis were selected in the cooler and, for that reason, the live and dressed weights could not be obtained.

The 750 live hogs weighed 130,830 pounds, or an average of 174 pounds per hog, and the average dressing yield was 68.44 per cent of live weight.

The hogs purchased on the East St. Louis market showed a difference in price of \$3.10 to \$3.40 per 100 pounds between oily and firm hogs. On the Fort Worth market the difference was 2 cents per pound.

Total amounts of meats used at Fort Worth and East St. Louis and loss caused by curing, smoking, and retaining.

	Fresh chilled weight (pounds).	Cooled smoked weight (pounds).	Loss: Chilled weight through smoke.		Weight at end of retaining period (pounds).	Loss: Smoked weight through retaining period.		Total loss chilled weight through retaining period.	
			Pounds.	Per cent.		Pounds.	Per cent.	Pounds.	Per cent.
Oily	14,470	13,741	729	2.30	12,466	1,275	9.28	2,004	13.85
Soft	11,447	10,764	683	5.97	9,624	1,140	10.59	1,823	15.92
Firm	15,909	15,263	646	4.06	13,706	1,557	10.20	2,203	13.85

RESULTS.[3]

The results of these tests, considering the large number, and the fact that they were conducted in two different packing houses, were encouragingly uniform. The shrinkage of the different cuts of the three grades of meat, however, varied in proportion to the size and thickness of the wholesale cut. Throughout all of these tests, both at Fort Worth and East St. Louis, there was a striking similarity in shrinkage between the loss of oily and firm meat. The soft meat, however, showed a heavier shrinkage than either the oily or firm.

GAIN IN WEIGHT CAUSED BY PUMPING AND CURING.

In the process of curing pork in the packing plants practically all of the pickle-cured meat is pumped with a curing solution to insure that it will reach the bones, and especially the joints. This, together with the absorption of the curing liquid in which the meat is kept from 30 to 60 days, increases the weight considerably. The pork cuts cured by the dry salt method, however, lost weight, although they had been pumped.

[3] The total combined results of the tests conducted at Fort Worth and East St. Louis are given here. For those who desire to make a more detailed study of the tests, a more complete report will be found in the Appendix.

In the pumping record in Table 1, it is shown that the increase in weight varies with the different wholesale cuts and the different grades of meat. Comparing the oily and firm meat, it is seen that the firm, dry salt bellies gained 2.86 per cent, and the firm pickle-cured picnics 5.23 per cent, while the oily dry-salt bellies gained 3.59 per cent and the oily pickle-cured picnics 6.78 per cent.

The pickle-cured bacon bellies were the only wholesale cuts that were not pumped. With the exception of the oily lots, however, the gain in cure was much more than in the case of any of the other cuts. The gain in cure was as follows: Oily, 4.43 per cent; soft, 7.92 per cent; firm, 9.62 per cent. In other words, the firm meat gained 5.19 per cent and the soft 3.49 per cent more than the oily. The gain in other cuts was much more uniform, and it should be noted that the great gain in the firm bacon bellies was counter-balanced by correspondingly heavy shrinkage in the smoke and during the retaining period.

LOSS IN SMOKE.

All cuts, regardless of how they were cured, lost weight while being smoked. This loss varied with the different cuts and grades of meat, but with every wholesale cut, except the picnics, the firm meat lost more weight than the oily lots. The soft meat in every case lost more than the firm.

The bacon bellies shrunk almost twice as much as the skinned hams. The shrinkage for all three grades of bacon bellies and skinned hams was as follows:

	Oily.	Soft.	Firm.
	Per cent.	*Per cent.*	*Per cent.*
Bellies	13.19	15.22	14.41
Skinned hams	7.49	7.85	7.84

When both gain and loss are considered, however, from the chilled weight through the smoke, the total loss for all of the cuts of the three grades was: Oily, 5.04 per cent; soft, 5.95 per cent; firm, 4.61 per cent. This indicates that if the meat were sold to the consumer immediately after being smoked the percentage loss of the firm product would have exceeded that of the oily by 0.43 and that of the soft by 1.34 per cent of the original weight. The large consuming centers, however, are too far from the packing plants to make this possible. Days, weeks, and sometimes many months elapse before meat is transferred from the packing plants to the consumer.

During the 19 to 21 days retaining period used in these tests (which was approximately the time required to handle the bulk of the meat) the firm and soft lots were found to shrink more than the

oily. This difference between the oily and firm was sufficient to counterbalance the losses of the oily meat sustained in the other processes.

SHRINKAGE DURING THE RETAINING PERIOD.

The general opinion is that the meat shrinks slowly and only a small amount after being smoked. The results of these tests, however, show that during the first 24 hours after the meat is taken out of smoke the shrinkage is comparatively heavy and that thereafter it continues to shrink, but at a constantly decreasing rate.

Referring to records during the retaining period, the figures appearing in Table 1 indicate that the different grades of meat shrunk during the 19 to 21-day retaining period as follows: Oily, 9.28 per cent; soft, 10.59 per cent; firm, 10.20 per cent. It will be noted, therefore, that, as was the case during the smoking period, the oily meat lost less than either the firm or the soft meat. This is significant, since the opinion has been widely held that during both periods oily meat shrinks more than soft or firm. It should also be noted that with pickle-cured bacon, in which there was a very noticeable difference in gain between the firm and oily lots in the cure, the firm meat lost 1.22 per cent more in smoke and 2.48 per cent more during the retaining period than the oily. In other words, the total loss from chilled weight to the end of the retaining period for firm and oily pickle-cured bellies was practically the same.

TOTAL LOSS IN OILY AND FIRM PORK THE SAME.

The total loss in wholesale smoked cuts from chilled weight to the end of the retaining period for the 14,470 pounds of oily and 15,909 pounds of firm pork was the same, or 13.85 per cent of the chilled weight. The soft meat, of which there was 11,447 pounds at the beginning, showed a shrinkage of 15.92 per cent, or 2.07 per cent more than the firm and oily. All shrinkage percentage comparisons are based upon the total weight of the meat considered. These results were contrary to what might have been expected, in view of the opinion generally held heretofore.

THE TRUE DIFFERENCE IN THE OILY, SOFT, AND FIRM PORK.

Although there is, so far as these tests would indicate, no difference in shrinkage, there is a very noticeable difference in the firmness of oily and firm pork after being chilled, and also a difference in the appearance of the meat before and after being cured.

In the fresh chilled condition, the oily carcass remains very soft and the fat has a slightly yellowish tinge. The carcass and the wholesale cuts handle very much the same as those from a warm carcass. The soft hog carcass is not firm and neither is it oily. The fat is white like that of a firm carcass.

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The firm carcass is solid and firm and the fat is pure white. The cuts are rigid and easily handled.

After the meat is cured and smoked, however, the difference between the oily and firm meat is not so noticeable, and it is difficult for the average person to detect one from the other from outward appearances. After being smoked and retained for 10 days the ham and shoulder cuts of the oily hogs were just as firm to the touch as similar cuts that had been classed as firm in the cooler. The oily bacon bellies, however, remained soft, were difficult to slice, and the constant oozing of the oil made them unsatisfactory to handle in retail trade.

FIG. 1.—Samples of lard from hogs graded as oily. Note that when the bottles are tilted the contents become adjusted to maintain a natural level, thus showing its liquid condition. Photograph taken immediately after samples were removed from a constant temperature of 30° C.

APPEARANCE OF THE MEAT.

According to these tests, the most serious objection to the oily meat was its appearance. Because the oil remained liquid in the cell, the fat of the thinly sliced bacon was almost transparent, giving to it a yellowish appearance instead of being pure white. When the meat was cut, oil in the broken cells smeared over the meat, making it unsatisfactory to handle. The lard also remained as oil instead of being firm and white. This fact is shown by Figures 1, 2, and 3, showing the samples of fat taken from oily, soft, and firm hogs. As shown in Figure 1, the samples of lard taken from oily hogs is liquid and transparent, as indicated by the dark color.

These samples, as well as those of soft and firm, had been held in an ice box at a temperature of 10° C., were removed and placed in a

constant-temperature box for 3 days at 30° C., were then taken out and quickly clamped in a tilted position and photographed, the aim being to get the picture when the fats were at a temperature of 30° C., in order to show the changed position of the fat in the soft and oily lots in comparison with the firm. It will be noted that the samples of fat from oily hogs in Figure 1 and those from soft hogs in Figure 2 moved to seek their level as water will. In the soft samples there is also the dark color, indicating that the fat is semiliquid and transparent. Since they did not all seek their own level to such an extent as did the oily, there is less difference between firm and soft than between firm and oily.

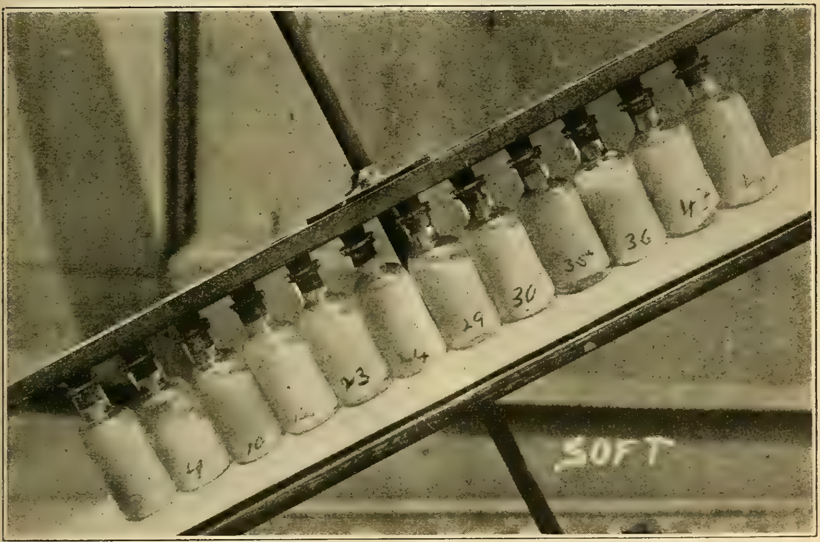

Fig. 2.—Samples of lard from hogs graded as soft. Note the varying degrees of semiliquid condition of the samples as shown by color, and a tendency of the contents to become adjusted to the new level. Samples Nos. 4, 10, 12, 23, 29, and 30 show a greater degree of liquidity than the others, particularly the samples on the extreme ends. Photograph taken immediately after samples were removed from a constant temperature of 30° C.

The fat of firm hogs will remain solid, as shown by Figure 3 and will therefore be a clear white.

These pictures show that there is a distinct difference in the lard of oily, soft, and firm hogs when held at a temperature of 30° C.

This objectionable feature of the oil remaining liquid in soft and oily meats is true in the case of bacon as well as in lard and to a less extent in the other cuts. The soft bacon was not oily, but when cut presented a soft, spongy appearance and was difficult to slice.

Although the bacon was decidedly inferior in appearance and without doubt was more difficult to sell, bacon comprises only a small percentage of the whole carcass, and for that reason it would seem that the discount made on live hogs should not be based entirely

on the difference in selling price of oily and firm bacon, but on the average difference in selling price of all of the cuts and by-products of the hog carcass.

On account of the inferior appearance and handling qualities of oily meat, together with the difference in shrinkage of the soft meat, the buyer of live hogs would seem to be justified in making some discount in price on those that chill out oily or soft. There were no noticeable differences in the keeping qualities or food value of the three grades of meat, but the unattractive appearance and unsatisfactory handling qualities of soft and oily pork make it more difficult to sell. If the difficulties in selling oily meat cause great delays the shrinkage will naturally be greater, because all meat continues to shrink from the time the animal is slaughtered until the carcass is consumed.

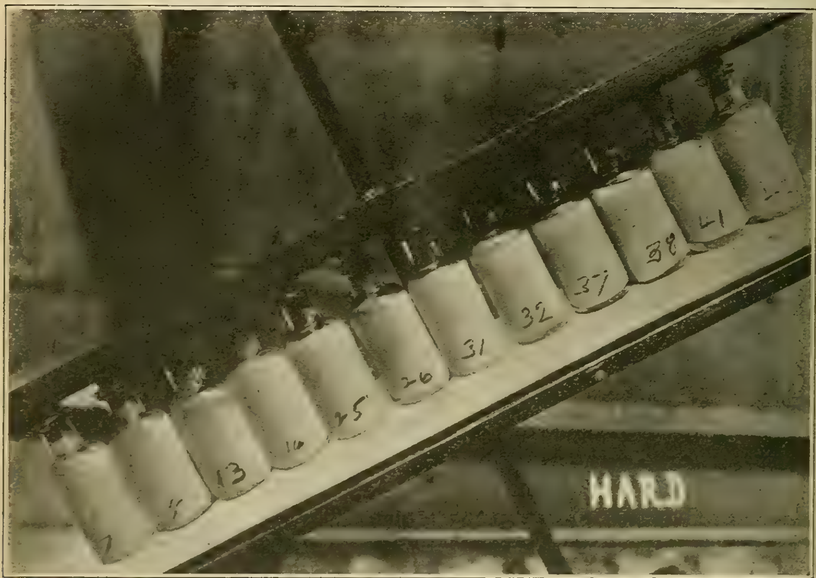

FIG. 3.—Samples of lard from hogs graded as firm or hard. Note that when the bottles are tilted the level of the contents does not change, showing that the lard is firm. Photographs taken immediately after lard was removed from a constant temperature 30° C.

PRICES OF THE THREE GRADES OF MEAT COMPARED.

The preliminary investigations conducted in Texas and Oklahoma to determine whether or not buyers of live hogs actually received a lower price for the pork and pork products from those that chill oily and soft were not extensive enough to allow definite conclusions to be drawn. They did show, however, that a considerably lower price was received for oily bacon, and slightly lower prices were received for lard and the wholesale cuts.

SUMMARY.

Investigation revealed that discounts ranging from 1½ to 7 cents per pound live weight were being made at the different live-stock markets for soft and oily hogs.

Hogs producing soft or oily carcasses can not be distinguished before slaughter from those yielding firm meat.

These tests did not show a distinct difference in the dressing percentages of soft, oily or firm hogs.

Shrinkage in the chill room was relatively the same for all classes of pork.

All cuts used (except pickle-cured bacon) were increased in weight 3.50 per cent to 11 per cent by pumping with a curing solution.

All pickle-cured meat gained in weight in cure.

The results of the tests on hams, skinned and not skinned, were practically the same. Both at East St. Louis and Fort Worth the records show that the oily meat gains less while in cure, but loses less in smoke and during the retaining period than does the firm. The hams classed as soft lose more than oily and less than firm through cure, but through smoke and the retaining period the oily skinned hams at Fort Worth and the regular oily hams at St. Louis shrunk less than the firm.

All meat cured by the dry salt method, except two lots of firm bellies and shoulders, lost weight in cure.

All of the oily meat gained less than firm from chilled weight through cure but, with the exception of picnics, all of the oily smoked cuts lost less weight than the firm during the smoking and retaining periods. All of the meat classed as soft lost more in smoke and during the retaining period than firm.

Oily ham and shoulder cuts, at the end of the retaining period, were just as firm to the touch as those that were classed in the cooler as firm. The appearance, however, was more glossy. The bellies (bacon) not only appeared more glossy and yellowish, but still remained soft and some of them seemed to be spongy.

The melting points of the leaf fats taken from the various lots show that the average of the oily samples was 34.70° F., while that for soft was 40.28° and for firm was 43.40°.

No difference was detected between oily, soft, and firm meats, relative to their keeping qualities, at the close of the retaining periods.

The results of the tests at Fort Worth show total percentage losses in weight of all the smoked wholesale cuts, from chilled weight through cure, smoke, and 19-day retaining period, as follows: Oily, 13.92 per cent; soft, 15.96 per cent; firm, 14.07 per cent.

Results of the tests conducted at East St. Louis show total losses in weight for same wholesale cuts through similar processes as follows: oily, 13.72 per cent; soft, 15.69 per cent; firm, 13.43 per cent.

The results of the tests in the two cities combined showed the same percentage shrinkage for oily and firm pork or 13.85 per cent. The shrinkage for the soft meat was 15.92 per cent, or 2.07 per cent of the total weight, more than the shrinkage of either the oily or firm.

Further investigations will be necessary before conclusions can be drawn regarding the justifiable discount that should be made on live hogs that dress out oily.

APPENDIX.

TABLE 1.—*Live weight and slaughter record of hogs used.*

	Lot No.	Number of hogs in lot.	Total live weight.	Total dressed weight.	Average live weight.	Dressing percentage.
Fort Worth:			*Pounds.*	*Pounds.*	*Pounds.*	
Bought as oily	1	25	4,120	2,829	164.8	68.66
	4	25	3,650	2,474	146.0	67.78
	7	25	3,300	2,247	132.0	68.09
	10	25	3,430	2,203	137.2	64.22
	13	25	4,930	3,535	197.2	71.70
	16	25	4,830	3,168	193.2	65.59
	19	25	4,450	3,035	178.0	68.20
	22	25	4,850	3,188	194.0	65.73
		200	33,560	22,679	167.8	67.58
Bought as soft	2	25	4,120	2,743	164.8	66.57
	5	25	3,550	2,422	142.0	68.22
	8	25	3,430	2,226	137.2	64.89
	11	25	3,630	2,422	145.2	66.68
	14	25	5,200	3,609	208.0	69.40
	17	25	5,090	3,426	203.6	67.30
	20	25	5,500	3,799	220.0	69.07
	23	25	4,730	3,197	189.6	67.59
		200	35,250	23,844	176.3	67.64
Bought as firm	3	25	3,950	2,720	158.0	68.86
	6	25	3,710	2,529	148.4	68.16
	9	25	3,460	2,397	138.4	69.27
	12	25	3,500	2,377	140.0	67.91
	15	25	5,070	3,576	202.8	70.53
	18	25	4,870	3,383	194.8	69.46
	21	25	5,020	3,452	200.8	68.76
	24	25	5,220	3,783	208.8	72.47
		200	34,800	24,217	174.0	69.82
East St. Louis:						
Bought as oily	1	25	4,860	3,401	194.0	69.97
	2	25	4,530	3,107	181.0	68.58
	3	25	4,300	2,939	172.0	68.34
		75	13,690	9,447	182.0	69.00
Bought as firm	1	25	4,630	3,241	185.0	70.00
	2	25	4,540	3,155	181.0	69.49
	3	25	4,360	2,962	174.0	67.93
		75	13,530	9,358	180.0	69.16
Total	......	750	130,830	89,545	....	....

These tables are given to show the average weight and dressing percentage of the hogs selected for each test. Although the totals indicate that the hogs bought as firm dressed a higher percentage than those that proved to be oily and soft, the individual lots which contained all oily or soft hogs did not show this difference. Other causes, such as finish and conformation, influence the dressing percentage, so that it can not be stated that these tests prove that firm hogs dress a higher percentage than oily ones. In the East St. Louis test dressing percentages were practically the same.

TABLE 2.—*Chill room record of all classes of carcasses used.*

FORT WORTH, BOUGHT AS SOFT OR OILY.

Lot No.	Dressed weight (pounds).	Chilled dressed weight (pounds).	Loss in chilling.	
			Pounds.	Per cent.
1	2,829	2,768, 25 oily 2,768	61	2.16
4	2,474	2,427 {6 firm 581 10 soft 958 9 oily 888	47	1.90
7	2,247	2,198 {1 soft 70 24 oily 2,126	49	2.18
10	2,203	2,146 {2 firm 189 5 soft 458 18 oily 1,499	57	2.59
13	3,535	3,452 {4 soft 490 21 oily 2,962	83	2.35
16	3,168	3,116 {3 firm 341 8 soft 1,166 14 oily 1,609	52	1.64
19	3,035	2,984 {8 firm 931 11 soft 1,305 6 oily 748	51	1.68
22	3,188	3,115 {7 soft 940 18 oily 2,175	73	2.29
	22,679	22,206 {19 firm 2,042 46 soft 5,387 135 oily 14,777	473	2.09
2	2,743	2,719, 25 oily 2,719	24	.87
5	2,422	2,383 {11 firm 1,022 8 soft 756 6 oily 605	39	1.61
8	2,226	2,182 {2 soft 181 23 oily 2,001	44	1.98
11	2,422	2,353 {16 firm 1,500 5 soft 511 4 oily 342	69	2.85
14	3,609	3,547 {19 firm 2,734 6 soft 813	62	1.72
17	3,426	3,376 {20 firm 2,684 2 soft 320 3 oily 372	50	1.46
20	3,799	3,714 {14 soft 1,949 11 oily 1,765	85	2.24
23	3,197	3,123 {18 soft 2,262 7 oily 861	74	2.31
	23,844	23,397 {66 firm 7,940 55 soft 6,792 79 oily 8,665	447	1.87

FORT WORTH, BOUGHT AS FIRM.

Lot No.	Dressed weight (pounds).	Chilled dressed weight (pounds).	Loss in chilling, pounds.	Loss in chilling, per cent.
3	2,720	2,681, 25 firm 2,681	39	1.43
6	2,529	2,478 {22 firm 2,156 2 soft 185 1 oily 137	51	2.02
9	2,397	2,343 {19 firm 1,802 3 soft 255 3 oily 296	54	2.25
12	2,377	2,315 {15 firm 1,399 3 soft 239 7 oily 677	62	2.6[illegible]
15	3,576	3,510 {24 firm 3,397 1 soft 113	66	1.8[illegible]
18	3,383	3,324, 25 firm 3,324	59	1.7[illegible]
21	3,452	3,399, 25 firm 3,399	53	1.5[illegible]
24	3,783	3,699, 25 firm 3,699	84	2.2[illegible]
	24,217	23,749 {155 firm 21,857 9 soft 792 11 oily 1,100	468	1.9[illegible]

Table 2.—*Chill room record of all classes of carcasses used*—Continued.

East St. Louis.

	Lot No.	Dressed weight (pounds).	Chilled dressed weight (pounds).	Loss in chilling.	
				Pounds.	Per cent.
Oily	1	3,401	3,362	39	1.15
	2	2,848	2,811	37	1.30
	3	2,939	2,896	43	1.46
		9,188	9,069	119	1.29
Firm	1	3,241	3,190	51	1.57
	2	3,155	3,126	29	.92
	3	2,962	2,910	52	1.76
		9,358	9,226	132	1.41

The average loss in the chill room as indicated by these tests was 1.74 per cent. There was a variation between the different lots of the same kind of meat and a smaller difference between the shrinkage of the three grades of meat. The total loss when all of the lots are considered both at Fort Worth and East St. Louis is practically the same for the three kinds of meat. In other words these tests do not show that oily and soft meat shrinks more than firm while being chilled.

Table 3.—*Pumping record of pickle-cured hams.*

Fort Worth.

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Gain by pumping.	
				Pounds.	Per cent.
Oily	1	601	642	41	6.82
	4	550	582	32	5.82
	7	448	487	39	8.71
	10	495	534	39	7.88
		2,094	2,245	151	7.21
Soft	2	547	586	39	7.13
	5	514	538	24	4.67
	8	488	527	39	7.99
	11	535	572	37	6.92
		2,084	2,223	139	6.67
Firm	3	544	575	31	5.70
	6	527	553	26	4.93
	9	492	530	38	7.72
	12	511	544	33	6.46
		2,074	2,202	128	6.17

East St. Louis.

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Gain by pumping.	
				Pounds.	Per cent.
Oily	1	687	725	38	5.53
	2	602	628	26	4.31
	3	596	617	21	3.52
	4	505	535	30	5.94
		2,390	2,505	115	4.81
Soft	2	605	629	24	3.97
Firm	1	659	693	34	5.16
	2	644	668	24	3.73
	3	612	634	22	3.59
	4	522	546	24	4.60
		2,437	2,541	104	4.27

TABLE 3.—*Pumping record of pickle-cured hams*—Continued.

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS PUMPING RECORDS ON PICKLE-CURED HAMS.

	Chilled fresh weight (pounds).	Pumped weight (pounds).	Gain by pumping.	
			Pounds.	Per cent.
Oily:				
Fort Worth	2,094	2,245	151	7.21
St. Louis	2,390	2,505	115	4.81
	4,484	4,750	266	5.93
Soft:				
Fort Worth	2,084	2,223	139	6.67
St. Louis	605	629	24	3.97
	2,689	2,852	163	6.06
Firm:				
Fort Worth	2,074	2,202	128	6.17
St. Louis	2,437	2,541	104	4.27
	4,511	4,743	232	5.14

The hams, after being trimmed and classified, were pumped with a curing solution that caused them to increase considerably in weight. This gain is usually uniform, but with some of the tests a variation was noted. In the Fort Worth tests this gain varied from 4.67 per cent to 7.99 per cent and at St. Louis from 3.52 to 5.94 per cent. It was noted that none of the meat in the St. Louis test gained as much by pumping as did the meat at Fort Worth. This was probably due to a difference in methods of the two packing plants. The combined total percentage gain at Fort Worth and East St. Louis was oily, 5.93; soft, 6.06; firm, 5.14.

TABLE 4.—*Curing records of pickle-cured hams.*

FORT WORTH.

	Lot No.	Weight in cure (pounds).	Number of days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain from chilled weight through cure.	
						Pounds.	Per cent.
Oily	1	642	61	16	641	40	6.66
	4	582	59	16	585	35	6.36
	7	487	61	14½	493	45	10.04
	10	534	59	14½	530	35	7.07
		2,245			2,249	155	7.40
Soft	2	586	61	16	596	49	8.96
	5	538	59	16	542	28	5.45
	8	527	61	14½	530	42	8.61
	11	572	59	14½	579	44	8.22
		2,223			2,247	163	7.82
Firm	3	575	61	16	589	45	8.27
	6	553	59	16	562	35	6.64
	9	530	61	14½	542	50	10.16
	12	544	59	14½	549	38	7.44
		2,202			2,242	168	8.10

TABLE 4.—*Curing records of pickle-cured hams*—Continued.

EAST ST. LOUIS.

	Lot No.	Weight in cure (pounds).	Number of days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain from chilled weight through cure.	
						Pounds.	Per cent.
Oily	1	725	55	72	717	30	4.37
	2	628	55	72	640	38	6.31
	3	617	55	96	633	37	6.21
	4	535	55	96	538	33	6.53
		2,505			2,528	138	5.77
Soft	2	629	55	72	641	36	5.95
Firm	1	693	55	72	701	42	6.37
	2	668	55	72	688	44	6.83
	3	634	55	96	650	38	6.21
	4	546	55	96	569	47	9.00
		2,541			2,608	171	7.02

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS CURING RECORDS ON PICKLE-CURED HAMS.

	Weight in cure (pounds).	Net weight of drained meat (pounds).	Gain from chilled weight through cure.	
			Pounds.	Per cent.
Oily:				
Fort Worth	2,245	2,249	155	7.40
St. Louis	2,505	2,528	138	5.77
Total	4,750	4,777	293	6.53
Soft:				
Fort Worth	2,223	2,247	163	7.82
St. Louis	629	641	36	5.95
Total	2,852	2,888	199	7.40
Firm:				
Fort Worth	2,202	2,242	168	8.10
St. Louis	2,541	2,608	171	7.02
Total	4,743	4,850	339	7.51

The hams in the Fort Worth test remained in the pickle cure 59 to 61 days and at St. Louis 55 days. In addition to the gain noted by pumping, the meat shows an additional gain while in the cure. The total percentage gain by pumping and cure is given in Table 4. This table shows that the gain of the firm meat in the St. Louis tests was similar to the gain of the oily and soft, but lower than the firm in the Fort Worth tests. The gains made by the soft and oily lots in the St. Louis test were much below those shown in the Fort Worth lots of the same grades of meat.

The Fort Worth and St. Louis combined percentage gain of all three grades of hams from chilled weight through cure was oily, 6.53; soft, 7.40; firm, 7.51. This shows that the firm meat gained 0.98 per cent of the total weight more than oily and 0.11 more than soft.

TABLE 5.—*Soaking record of pickle-cured hams.*

FORT WORTH.

	Lot No.	Weight of meat in soak (pounds).	Time meat soaked. Hours.	Time meat soaked. Minutes.	Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
Oily	1	641	4	34	641	80	0
	4	585	4	26	587	80	2
	7	493	4	30	489	74	−4
	10	530	4	26	535	74	5
		2,249			2,252		3
Soft	2	596	4	34	598	80	2
	5	542	4	26	549	80	7
	8	530	4	30	531	74	1
	11	579	4	26	582	74	3
		2,247			2,260		13
Firm	3	589	4	34	590	80	1
	6	562	4	26	565	80	3
	9	542	4	30	545	74	3
	12	549	4	26	555	74	6
		2,242			2,255	13	13

EAST ST. LOUIS.

	Lot No.	Weight of meat in soak (pounds).	Time meat soaked. Hours.	Time meat soaked. Minutes.	Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
Oily	1	717	4	15	726	70	9
	2	640	3	23	644	70	4
	3	633	3	23	637	70	4
	4	538	3	27	543	70	5
		2,528			2,550		22
Soft	2	641	3	23	640	70	−1
Firm	1	701	4	15	705	70	4
	2	688	3	23	686	70	−2
	3	650	3	23	656	70	6
	4	569	3	27	567	70	−2
		2,608			2,614		6

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS SOAKING RECORDS ON HAMS.

	Weight of meat in soak.	Net weight of drained meat out of soak.	Gain or loss in soak.
Oily:	*Pounds.*	*Pounds.*	*Pounds.*
Fort Worth	2,249	2,252	3
East St. Louis	2,528	2,550	22
Total	4,777	4,802	25
Soft:			
Fort Worth	2,247	2,260	13
East St. Louis	641	640	−1
Total	2,888	2,900	12
Firm:			
Fort Worth	2,242	2,255	13
East St. Louis	2,608	2,614	6
Total	4,850	4,869	19

After the meat was taken out of the pickle solution it was drained, weighed, and placed in a soaking solution 3 to 4 hours, the tests at Fort Worth remaining in the soak 4 hours and those at East St. Louis, with the exception of one test, 3 hours. After the meat came out of soak it was allowed to drain and then was weighed and hung on iron racks to be smoked.

The soaking records also varied, especially in the oily lots, therefore they are not considered to be of great importance.

TABLE 6.—*Smoke record of pickle-cured hams.*

FORT WORTH.

	Lot No.	Weight in smoke (pounds).	Hours smoked.	Temperature of smoke-house at— Beginning (° F.).	Temperature of smoke-house at— Close (° F.).	Net weight of cooled meat (pounds).	Total loss in smoke. Pounds.	Total loss in smoke. Per cent.	Total loss from chilled fresh weight through smoke. Pounds.	Total loss from chilled fresh weight through smoke. Per cent.
Oily	1	641	21½	82	124	588	53	8.27	13	2.16
	4	587	21½	82	124	547	40	6.81	3	.55
	7	489	20	80	125	448	41	8.38	0	.00
	10	535	20	80	125	485	50	9.34	10	2.02
		2,252	....	....	....	2,068	184	8.17	26	1.24
Soft	2	598	21½	82	124	547	51	8.53	0	.00
	5	549	21½	82	124	506	43	7.83	8	1.56
	8	531	20	80	125	480	51	9.60	8	1.64
	11	582	20	80	125	530	52	8.93	5	.93
		2,260	....	....	....	2,063	197	8.71	21	1.01
Firm	3	590	21½	82	124	543	47	7.97	1	.18
	6	565	21½	82	124	519	46	8.14	8	1.52
	9	545	20	80	125	492	53	9.72	0	.00
	12	555	20	80	125	502	53	9.54	9	1.76
		2,255	....	....	....	2,056	199	8.82	18	.87

EAST ST. LOUIS.

	Lot No.	Weight in smoke (pounds).	Hours smoked.	Temperature of smoke-house at— Beginning (° F.).	Temperature of smoke-house at— Close (° F.).	Net weight of cooled meat (pounds).	Total loss in smoke. Pounds.	Total loss in smoke. Per cent.	Total loss from chilled fresh weight through smoke. Pounds.	Total loss from chilled fresh weight through smoke. Per cent.
Oily	1	726	33	80	66	678	48	6.61	9	1.31
	2	644	32	69	76	592	52	8.07	10	1.66
	3	637	35	79	82	585	52	8.16	11	1.84
	4	543	35	83	92	498	45	8.29	7	1.74
		2,550	....	....	....	2,353	197	7.73	37	1.55
Soft	2	640	32	69	76	586	54	8.44	19	3.14
Firm	1	705	33	80	66	648	57	8.09	11	1.67
	2	686	32	69	76	635	51	7.43	9	1.40
	3	656	35	79	82	597	59	8.99	15	2.45
	4	567	35	83	92	519	48	8.47	3	.57
		2,614	....	....	....	2,399	215	8.22	38	1.56

TABLE 6.—*Smoke record of pickle-cured hams*—Continued.

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS SMOKE RECORDS ON PICKLE-CURED HAMS.

	Weight in smoke (pounds).	Net weight of cooled meat (pounds).	Total loss in smoke.		Total loss from chiled fresh weight through smoke.	
			Pounds.	Per cent.	Pounds.	Per cent.
Oily:						
Fort Worth	2,252	2,068	184	8.17	26	1.24
St. Louis	2,550	2,353	197	7.73	37	1.55
Total	4,802	4,421	381	7.93	63	1.43
Soft:						
Fort Worth	2,260	2,063	197	8.72	21	1.01
St. Louis	640	586	54	8.44	19	3.14
Total	2,900	2,649	251	8.66	40	1.49
Firm:						
Fort Worth	2,255	2,056	199	8.82	18	.87
St. Louis	2,614	2,399	215	8.22	38	1.56
Total	4,869	4,455	414	8.50	56	1.24

The meat in the Fort Worth tests remained in smoke 20 to 21½ hours at a temperature of 124 to 125° F., while in the St. Louis tests it remained in smoke 32 to 35 hours.

The loss in smoke at the two plants, however, did not vary greatly. The average combined losses at the two plants were: Oily, 7.93 per cent; soft, 8.66 per cent; firm, 8.50 per cent. This shows that the firm lost 0.57 per cent and soft 0.73 per cent more than the oily.

When the gain by pumping and curing was considered with the loss in smoke the total loss from chilled weight through smoke was less than 15 per cent for each of the different grades of meat.

TABLE 7.—*Retaining period of pickle-cured hams.*

FORT WORTH.

	Lot No.	Weight cooled smoked meat (lbs.).	Weight of meat 24 hours after smoked (lbs.).	Net weight at end of—		Loss during retaining period.		Chilled fresh weight through retaining period.		
				6 days (lbs.).	19 days (lbs.).	Lbs.	Per cent.	Lbs.	Per cent.	Yield.
Oily	1	588	584	560	533	55	9.35	68	11.31	88.69
	4	547	543	524	503	44	8.04	47	8.54	91.46
	7	448	443	430	400	48	10.71	48	10.71	89.29
	10	485	479	458	422	63	12.99	73	14.75	85.25
		2,068	2,049	1,972	1,858	210	10.15	236	11.27	88.73
Soft	2	547	540	519	490	57	10.42	57	10.42	89.58
	5	506	502	482	459	47	9.29	55	10.70	89.30
	8	480	473	456	417	63	13.12	71	14.55	85.45
	11	530	525	504	465	65	12.26	70	13.08	86.92
		2,063	2,040	1,961	1,831	232	11.25	253	12.14	87.86
Firm	3	543	538	517	490	53	9.76	54	9.93	90.07
	6	519	513	490	462	57	10.98	65	12.33	87.67
	9	492	482	470	430	62	12.60	62	12.60	87.40
	12	502	498	479	439	63	12.55	72	14.09	85.91
		2,056	2,030	1,956	1,821	235	11.43	253	12.20	87.80

TABLE 7.—*Retaining period of pickle-cured hams*—Continued.

EAST ST. LOUIS.

	Lot No.	Weight cooled smoked meat (lbs.).	Weight of meat 24 hours after smoked (lbs.).	Net weight at end of—		Loss during retaining period.		Chilled fresh weight through retaining period.		
				6 days (lbs.).	19 days (lbs.).	Lbs.	Per cent.	Lbs.	Per cent.	Yield.
Oily	1	678	675	660	[1] 632	46	6.78	55	8.00	92.00
	2	592	587	565	[1] 536	56	9.46	66	10.96	89.04
	3	585	580	561	[1] 529	56	9.57	67	11.24	88.76
	4	498	493	476	[1] 446	52	10.44	59	11.68	88.32
		2,353	2,335	2,262	[1] 2,143	210	8.92	247	10.33	89.67
Soft	2	586	581	557	[1] 525	61	10.41	80	13.22	86.78
Firm	1	648	643	622	[1] 593	55	8.49	66	10.02	89.98
	2	635	629	605	[1] 575	60	9.45	69	10.71	89.29
	3	597	590	566	[1] 530	67	11.22	82	13.40	86.60
	4	519	513	496	[1] 464	55	10.60	58	11.11	88.89
		2,399	2,375	2,289	[1] 2,162	237	9.88	275	11.28	88.72

[1] 21 days.

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS RETAINING RECORDS ON PICKLE-CURED HAMS.

	Weight cooled smoked meat (lbs.).	Weight of meat 24 hours after smoked (lbs.).	Net weight at end of—		Loss during retaining period		Chilled fresh weight through retaining period.		
			6 days (lbs.).	19 days (lbs.).	Lbs.	Per cent.	Lbs.	Per cent.	Yield.
Oily:									
Fort Worth	2,068	2,049	1,972	1,858	210	10.15	236	11.27	88.73
East St. Louis	2,353	2,335	2,262	[1] 2,143	210	8.92	247	10.33	89.67
Total	4,421	4,384	4,234	4,001	420	9.50	483	10.77	89.23
Soft:									
Fort Worth	2,063	2,040	1,961	1,831	232	11.25	253	12.14	87.86
East St. Louis	586	581	557	[1] 525	61	10.41	80	13.22	86.78
Total	2,649	2,621	2,518	2,356	293	11.06	333	12.38	87.62
Firm:									
Fort Worth	2,056	2,030	1,956	1,821	235	11.43	253	12.20	87.80
East St. Louis	2,399	2,375	2,289	[1] 2,162	237	9.88	275	11.28	88.72
Total	4,455	4,405	4,245	3,983	472	10.59	528	11.70	88.30

[1] 21 days.

The oily meat at both Fort Worth and East St. Louis lost less weight than the firm during the retaining period, while the soft lost less at East St. Louis but slightly more at Fort Worth. The total percentage loss during the retaining period was: Oily, 9.50 per cent; soft, 11.06 per cent; firm, 10.59 per cent. Adding to this the loss at the end of the smoking process it is shown that the total shrinkage in per cent on hams from the fresh chilled weight to the end of the retaining period was: Oily, 10.77 per cent; soft, 12.38 per cent; firm 11.70 per cent; making a yield of meat for oily, 89.23 per cent; soft, 87.62 per cent; firm, 88.30 per cent. This shows that the oily lost 0.93 per cent less than firm and 1.61 per cent less than soft.

SKINNED HAMS.

In the territory of Fort Worth, Tex., a considerable demand existed for skinned hams; consequently, several tests were conducted in order to determine the difference in shrinkage, if any, between skinned hams and those not skinned. They were selected and divided into lots according to the way they were classed in the cooler, as were the regular hams.

It will be noticed that the oily hams increased 5.41 per cent, soft 4.99 per cent, and firm 4.63 per cent.

The increase in weight, however, in cure, plus the pumping, was reversed, as shown by the following percentages of the totals: Oily, 6.62 per cent; soft, 6.85 per cent; firm, 9.15 per cent. In other words, the oily gained 1.21 per cent, soft 1.86 per cent, and firm 4.52 per cent while in cure.

One of the objections held against oily pork was that it did not take the cure or increase in weight as did firm pork, and these figures, as well as the following data, show this to be true.

In the tests with 12 lots of skinned hams the firm meat increased 2.53 per cent more than the oily and 2.30 per cent more than the soft, from chilled weight through cure.

TABLE 8.—*Pumping record of pickle-cured skinned hams—Fort Worth.*

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Gain by pumping.	
				Pounds.	Per cent.
Oily	13	655	691	36	5.50
	16	682	718	36	5.28
	19	628	659	31	4.94
	22	602	638	36	5.98
		2,567	2,706	139	5.41
Soft	14	774	810	36	4.65
	17	705	739	34	4.82
	20	666	699	33	4.95
	23	642	678	36	5.61
		2,787	2,926	139	4.99
Firm	15	685	717	32	4.67
	18	584	613	29	4.97
	21	761	792	31	4.07
	24	648	680	32	4.94
		2,678	2,802	124	4.63

TABLE 9.—*Curing record of pickle-cured skinned hams—Fort Worth.*

	Lot No.	Weight in cure (pounds).	Days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain from chilled weight through cure.	
						Pounds.	Per cent.
Oily	13	691	59	16	695	40	6.11
	16	718	58	16	723	41	6.01
	19	659	61	15½	675	47	7.48
	22	638	60	15½	644	42	6.98
		2,696			2,737	170	6.62
Soft	14	810	59	16	819	45	5.81
	17	739	58	16	753	48	6.81
	20	699	61	15½	716	50	7.51
	23	678	60	15½	690	48	7.48
		2,926			2,978	191	6.85
Firm	15	717	59	16	739	54	7.88
	18	613	58	16	646	62	10.62
	21	792	61	15½	821	60	7.88
	24	680	60	15½	717	69	10.65
		2,802			2,923	245	9.15

TABLE 10.—*Soaking record of pickle-cured skinned hams—Fort Worth.*

	Lot No.	Weight of meat in soak (pounds).	Time meat soaked.		Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
			Hours.	Minutes.			
Oily	13	695	3	56	693	76	−2
	16	723	3	52	726	76	3
	19	675	4	4	673	72	−2
	22	644	4	....	645	72	1
		2,737	....	....	2,737	....	0
Soft	14	819	3	56	820	76	1
	17	753	3	52	751	76	−2
	20	716	4	4	717	72	1
	23	690	4	....	691	72	1
		2,978	....	....	2,979	....	1
Firm	15	739	3	56	736	76	−3
	18	646	3	52	643	76	−3
	21	821	4	4	817	72	−4
	24	717	4	....	714	72	−3
		2,923	....	....	2,910	....	−13

TABLE 11.—*Smoke record of pickle-cured skinned hams—Fort Worth.*

	Lot No.	Weight in smoke (lbs.).	Hours smoked.	Temperature of smoke house at—		Net weight of cooled meat (lbs.).	Total loss in smoke.		Total loss or gain from chilled fresh weight through smoke.	
				Beginning.	Close.		Lbs.	Per cent.	Lbs.	Per cent.
				° F.	° F.					
Oily	13	693	23	82	128	650	43	6.20	5	.76
	16	726	23	82	128	678	48	6.61	4	.59
	19	673	19	88	132	616	57	8.47	12	1.91
	22	645	19	88	132	588	57	8.84	14	2.33
		2,737	....	....	....	2,532	205	7.49	35	1.36
Soft	14	820	23	82	128	764	56	6.83	10	1.29
	17	751	23	82	128	697	54	7.19	8	1.13
	20	717	19	88	132	651	66	9.21	15	2.25
	23	691	19	88	132	633	58	8.39	9	1.40
		2,979	....	....	....	2,745	234	7.85	42	1.51
Firm	15	736	23	82	128	687	49	6.66	+2	+.29
	18	643	23	82	128	596	47	7.31	+12	+2.05
	21	817	19	88	132	747	70	8.57	14	1.84
	24	714	19	88	132	652	62	8.68	+4	+.62
		2,910	....	....	....	2,682	228	7.84	+4	+.15

The total percentage loss in smoke of the skinned hams shown in Table 11 was: Oily, 7.49 per cent; soft, 7.85 per cent; firm, 7.84 per cent. This loss is about 1 per cent less than the loss for hams not skinned. The loss from chilled weight through smoke was: Oily, 1.36 per cent; soft, 1.51 per cent. The firm lots made a slight gain instead of losing in weight, due to a very large increase in weight of lots 18 and 24 while in cure.

TABLE 12.—*Retaining period of pickle-cured skinned hams, Fort Worth.*

	Lot No.	Weight cooled smoked meat (pounds).	Weight of meat 24 hours after smoked (pounds).	Net weight at end of—		Loss during retaining period.		Green weight through retaining period.		
								Total loss.		
				6 days (pounds).	19 days (pounds).	Pounds.	Per cent.	Pounds.	Per cent.	Per cent yield.
Oily	13	650	643	626	591	59	9.08	64	9.77	90.23
	16	678	669	646	598	80	11.80	84	12.32	87.68
	19	616	616	596	564	52	8.44	64	10.19	89.81
	22	588	581	553	514	74	12.59	88	14.62	85.38
		2,532	2,509	2,421	2,267	265	10.47	300	11.68	88.32
Soft	14	764	759	732	689	75	9.82	85	10.98	89.02
	17	697	691	664	618	79	11.33	87	12.34	87.66
	20	651	643	614	569	82	12.60	97	14.56	85.44
	23	633	622	593	551	82	12.95	91	14.17	85.83
		2,745	2,715	2,603	2,427	318	11.58	360	12.92	87.08
Firm	15	687	680	659	613	74	10.77	72	10.51	89.49
	18	596	591	570	535	61	10.23	49	8.39	91.61
	21	747	738	704	660	87	11.65	101	13.27	86.73
	24	652	644	615	576	76	11.66	72	11.11	88.89
		2,682	2,653	2,548	2,384	298	11.11	294	10.98	89.02

During the retaining period of the skinned hams the loss was oily, 10.47 per cent; soft, 11.58 per cent; firm 11.11 per cent, which shows that oily meat shrunk 0.64 per cent of the total weight less than firm and 1.11 per cent less than soft.

The total shrinkage from chilled weight through the 19-day retaining period as shown in Table 12 was oily, 11.68 per cent; soft, 12.92 per cent; firm, 10.98 per cent. In other words, the oily lost 0.7 per cent and soft 1.94 per cent more than the hams classed as firm.

Comparing the total shrinkage of skinned hams with the total shrinkage of hams not skinned, it is found that—

Oily skinned hams lost 0.41 per cent more than oily hams not skinned.
Soft skinned hams lost 0. 78 per cent more than soft hams not skinned.
Firm skinned hams lost 1.22 per cent less than firm hams not skinned.

PICNICS (SHOULDERS) PICKLE CURED.

The demand for certain cuts of the shoulders made it impracticable to make tests on the same cut at both Fort Worth and East St. Louis; consequently, all of the tests at Fort Worth, with one exception, were made with the shoulder cut known as New Orleans shoulder and cured by the dry-salt method, while the cut known as picnic was used at East St. Louis and cured in sweet pickle. The shoulder cut of one test at Fort Worth was made into picnics and was pickle cured.

The pumping records of the one test of pickle-cured picnics at Fort Worth show that the percentage gain was almost double that of the East St. Louis tests of the same cut. The variation is not great between firm, soft, and oily at each plant, but it does show how one plant varies from another.

TABLE 13.—*Pumping record of pickle-cured picnics.*

FORT WORTH.

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Gain by pumping.	
				Pounds.	Per cent.
Oily	1	257	283	26	10.12
Soft	2	232	258	26	11.21
Firm	3	238	260	22	9.24

EAST ST. LOUIS.

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Pounds.	Per cent.
Oily	1	241	255	14	5.81
	2	251	268	17	6.77
	3	242	252	10	4.31
	4	189	202	13	5.88
		923	977	54	5.85
Soft	2	271	288	17	6.27
Firm	1	272	286	14	5.15
	2	267	281	14	5.24
	3	267	277	10	3.75
	4	294	304	10	3.40
		1,100	1,148	48	4.36

COMBINED RESULT OF FORT WORTH AND EAST ST. LOUIS PUMPING RECORDS ON PICKLE-CURED PICNICS.

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Pounds.	Per cent.
Oily:					
Fort Worth		257	283	26	10.12
East St. Louis		923	977	54	5.85
		1,180	1,260	80	6.78
Soft:					
Fort Worth		232	258	26	11.21
East St. Louis		271	288	17	6.27
		503	546	43	8.55
Firm:					
Fort Worth		238	260	22	9.24
East St. Louis		1,100	1,148	48	4.36
		1,338	1,408	70	5.23

TABLE 14.—*Curing record of pickle-cured picnics.*

FORT WORTH.

	Lot No.	Weight in cure (pounds).	Number of days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain from chilled weight through cure.	
						Pounds.	Per cent.
Oily	1	283	33	17	282	25	9.73
Soft	2	258	33	17	262	30	12.93
Firm	3	260	33	17	265	27	11.34

TABLE 14.—*Curing record of pickle-cured picnics*—Continued.

EAST ST. LOUIS.

	Lot No.	Weight in cure (pounds).	Number of days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain from chilled weight through cure.	
						Pounds.	Per cent.
Oily	1	255	30	72	250	9	3.73
	2	268	30	72	265	14	5.58
	3	252	31	72	259	17	7.02
	4	202	31	72	200	11	5.82
		977			974	51	5.53
Soft	2	288	30	72	297	26	9.59
Firm	1	286	30	72	289	17	6.25
	2	281	30	72	286	19	7.12
	3	277	31	72	283	16	5.99
	4	304	31	72	317	23	7.82
		1,148			1,175	75	6.82

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS CURING RECORDS ON PICKLE-CURED PICNICS.

Oily:							
Fort Worth		283			282	25	9.73
East St. Louis		977			974	51	5.53
		1,260			1,256	76	6.44
Soft:							
Fort Worth		258			262	30	12.93
East St. Louis		288			297	26	9.59
		546			559	56	11.13
Firm:							
Fort Worth		260			265	27	11.34
East St. Louis		1,148			1,175	75	6.82
		1,408			1,440	102	7.62

The shoulder cut known as the picnic is a small piece of meat, therefore is not allowed to remain in the cure as long as the hams. In the Fort Worth tests they remained 33 days in cure and at East St. Louis 30 to 31 days.

The percentage gain by pumping and curing was very much the same as that for the hams in the oily and firm grades at East St. Louis, where four lots of each kind of meat were tested, but in the test where only one lot of each grade was used the gain was very much greater. The combined totals, however, show that the oily gained 6.44 per cent, soft 11.13 per cent, and firm 7.62 per cent, or the firm 1.18 per cent and soft 3.51 per cent more than the oily.

At certain seasons of the year some of this kind of pork is sold to the trade without being smoked. These results indicate that when this is done the meat actually gains from 5.53 per cent to 12.93 per cent, depending upon the grade of meat.

TABLE 15.—*Soaking record of pickle-cured picnics.*

FORT WORTH.

	Lot No.	Weight of meat in soak (pounds).	Time meat soaked.		Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
			Hours.	Minutes.			
Oily	1	282	2	33	284	80	2
Soft	2	262	2	33	257	80	−5
Firm	3	265	2	33	268	80	3

EAST ST. LOUIS.

	Lot No.	Weight of meat in soak (pounds).	Hours.	Minutes.	Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
Oily	1	250	1	45	252	70	2
	2	265	1	55	268	70	3
	3	259	1	55	261	70	2
	4	200	2	....	200	70	0
		974	....	....	981	....	7
Soft	2	297	1	55	295	70	−2
Firm	1	289	1	45	289	70	0
	2	286	1	55	287	70	1
	3	283	1	55	281	70	−2
	4	317	2	....	314	70	−3
		1,175	....	....	1,171	....	−4

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS SOAKING RECORDS ON PICKLE-CURED PICNICS.

	Lot No.	Weight of meat in soak (pounds).	Hours.	Minutes.	Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
Oily:							
Fort Worth	......	282	....	....	284	....	2
St. Louis	......	974	....	....	981	....	7
		1,256	....	....	1,265	....	9
Soft:							
Fort Worth	......	262	....	....	257	....	−5
St. Louis	......	297	....	....	295	....	−2
		559	....	....	552	....	−7
Firm:							
Fort Worth	......	265	....	....	268	....	3
St. Louis	......	1,175	....	....	1,171	....	−4
		1,440	....	....	1,439	....	−1

TABLE 16.—*Smoke record of pickle-cured picnics.*

FORT WORTH.

	Lot No.	Weight in smoke (pounds).	Hours smoked.	Temperature of smokehouse at—		Net weight of cooled meat (pounds).	Total loss in smoke.		Total loss from chilled fresh weight through smoke.	
				Beginning (° F.).	Close (° F.).		Pounds.	Per cent.	Pounds.	Per cent.
Oily	1	284	28	85	125	248	36	12.68	9	3.50
Soft	2	257	28	85	125	226	31	12.06	6	2.59
Firm	3	268	28	85	125	235	33	12.31	3	1.26

TABLE 16.—*Smoke record of pickle-cured picnics*—Continued.

EAST ST. LOUIS.

	Lot No.	Weight in smoke (pounds).	Hours smoked.	Temperature of smoke-house at— Beginning (° F.)	Temperature of smoke-house at— Close (° F.).	Net weight of cooled meat (pounds).	Total loss in smoke. Pounds.	Total loss in smoke. Per cent.	Total loss from chilled fresh weight through smoke. Pounds.	Total loss from chilled fresh weight through smoke. Per cent.
Oily	1	252	34½	76	63	225	27	10.71	16	6.64
	2	268	36	62	74	239	29	10.83	12	4.78
	3	261	34½	82	68	228	33	12.64	14	5.79
	4	200	32½	72	70	179	21	10.50	10	5.29
		981	....	....	....	871	110	11.21	52	5.63
Soft	2	295	36	62	74	261	34	11.53	10	3.69
Firm	1	289	34½	76	63	255	34	11.76	17	6.25
	2	287	36	62	74	257	30	10.45	10	3.75
	3	281	34½	82	68	248	33	11.74	19	7.12
	4	314	32½	72	70	286	28	8.92	8	2.72
		1,171	....	....	....	1,046	125	10.67	54	4.91

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS SMOKE RECORDS ON PICKLE-CURED PICNICS.

Oily:										
Fort Worth	.....	284	....	....	....	248	36	12.68	9	3.50
St. Louis	.....	981	....	....	....	871	110	11.21	52	5.63
		1,265	....	....	....	1,119	146	11.54	61	5.17
Soft:										
Fort Worth	.....	257	....	....	....	226	31	12.06	6	2.59
St. Louis	.....	295	....	....	....	261	34	11.53	10	3.69
		552	....	....	....	487	65	11.78	16	3.18
Firm:										
Fort Worth	.....	268	....	....	....	235	33	12.31	3	1.26
St. Louis	.....	1,171	....	....	....	1,046	125	10.67	54	4.91
		1,439	....	....	....	1,281	158	10.98	57	4.26

The smoke records of picnics show that the loss in Fort Worth tests was greater than at St. Louis and the oily meats shrank more than the firm.

The combined results were as follows: Oily, 11.54 per cent; soft, 11.78 per cent; firm, 10.98 per cent. The loss from chilled weight through smoke for both Fort Worth and East St. Louis show that the oily shrank 0.91 per cent more than the firm and 1.99 per cent more than the soft.

TABLE 17.—*Retaining period of pickle-cured picnics.*

FORT WORTH.

	Lot No.	Net weight cooled smoked (lbs.).	Net weight of meat 24 hours after (lbs.).	Net weight at end of— 6 days (lbs.).	Net weight at end of— 21 days (lbs.).	Loss during retaining. Pounds.	Loss during retaining. Per cent.	Green weight through retaining period. Loss (lbs.).	Green weight through retaining period. Per cent— Loss.	Green weight through retaining period. Per cent— Yield.
Oily	1	248	[1] 245	229	[2] 211	37	14.92	46	17.90	82.10
Soft	2	226	[1] 224	209	[2] 191	35	15.49	41	17.67	82.33
Firm	3	235	[1] 234	219	[2] 203	32	13.62	35	14.71	85.29

TABLE 17.—*Retaining period of pickle-cured picnics*—Continued.

EAST ST. LOUIS.

	Lot No.	Net weight cooled smoked (lbs.).	Net weight of meat 24 hours after (lbs.)	Net weight at end of—		Loss during retaining.		Green weight through retaining period.		
				6 days (lbs.).	21 days (lbs.).	Pounds.	Per cent.	Loss (lbs.).	Per cent—	
									Loss.	Yield.
Oily	1	225	223	219	201	24	10.67	40	16.60	83.40
	2	239	235	224	208	31	12.97	43	17.13	82.87
	3	228	223	216	200	28	12.28	42	17.36	82.64
	4	179	173	164	150	29	16.20	39	20.63	79.37
		871	854	823	759	112	12.86	164	17.77	82.23
Soft	1	261	257	243	223	38	14.56	48	17.71	82.29
Firm	1	255	253	246	226	29	11.37	46	16.91	83.09
	2	257	253	242	227	30	11.67	40	14.98	85.02
	3	248	242	233	215	33	13.31	52	19.48	80.52
	4	286	280	268	250	36	12.59	44	14.97	85.03
		1,046	1,028	989	918	128	12.24	182	16.55	83.45

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS RETAINING RECORDS ON PICKLE-CURED PICNICS.

Oily:										
Fort Worth		248	245	229	211	37	14.92	46	17.90	82.10
East St. Louis		871	854	823	759	112	12.86	164	17.77	82.23
		1,119	1,099	1,052	970	149	13.32	210	17.80	82.20
Soft:										
Fort Worth		226	224	209	191	35	15.49	41	17.67	82.33
East St. Louis		261	257	243	223	38	14.56	48	17.71	82.29
		487	481	452	414	73	14.99	89	17.69	82.31
Firm:										
Fort Worth		235	234	219	203	32	13.62	35	14.71	85.29
East St. Louis		1,046	1,028	989	918	128	12.24	182	16.55	83.45
		1,281	1,262	1,208	1,121	160	12.49	217	16.22	83.78

[1] 36 hours. [2] 18 days.

The percentage shrinkage during the retaining period, as shown in the combined results, was: Oily, 13.32 per cent; soft, 14.99 per cent; firm, 12.49 per cent; or the oily picnics shrank 0.83 per cent and the soft 2.5 per cent more than the firm.

The total loss from chilled weight through the retaining period was heavier for picnics than for any of the other cuts. This wholesale cut shows that oily meat shrank 1.58 per cent and soft 1.47 per cent more than firm.

TABLE 18.—*Curing record of pickle-cured bellies (bacon).*

FORT WORTH.

	Lot No.	Chilled fresh weight (pounds).	Number of days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain from chilled weight through cure. Pounds.	Gain from chilled weight through cure. Per cent.
Oily	1	444	32	16	458	14	3.15
	4	559	31	16	578	19	3.40
	7	436	42	19	465	29	6.65
	10	378	42	19	396	18	4.76
		1,817			1,897	80	4.40
Soft	2	470	32	16	512	42	8.94
	5	466	31	16	495	29	6.22
	8	399	42	19	431	32	8.02
	11	432	42	19	466	34	7.87
		1,767			1,904	137	7.75
Firm	3	501	32	16	550	49	9.78
	6	476	31	16	512	36	7.56
	9	442	42	19	490	48	10.86
	12	458	42	19	503	45	9.83
		1,877			2,055	178	9.48

EAST ST. LOUIS.

	Lot No.	Chilled fresh weight (pounds).	Number of days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain from chilled weight through cure. Pounds.	Gain from chilled weight through cure. Per cent.
Oily	1	524	30	72	534	10	1.91
	2	439	30	72	465	26	5.92
	3	429	31	72	457	28	6.53
	4	316	31	72	328	12	3.80
		1,708			1,784	76	4.45
Soft	2	443	30	72	481	38	8.58
Firm	1	550	30	72	598	48	8.73
	2	509	30	72	557	48	9.43
	3	439	31	72	476	37	8.43
	4	585	31	72	655	70	11.97
		2,083			2,286	203	9.75

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS CURING RECORDS ON BELLIES (BACON).

	Chilled fresh weight (pounds).	Number of days in cure.	Hours meat drained.	Net weight of drained meat (pounds).	Gain Pounds.	Gain Per cent.
Oily:						
Fort Worth	1,817			1,897	80	4.40
East St. Louis	1,708			1,784	76	4.45
	3,525			3,681	156	4.43
Soft:						
Fort Worth	1,767			1,904	137	7.75
East St. Louis	443			481	38	8.58
	2,210			2,385	175	7.92
Firm:						
Fort Worth	1,877			2,055	178	9.48
East St. Louis	2,083			2,286	203	9.75
	3,960			4,341	381	9.62

Four tests were made on pickle-cured bellies (bacon) at each of the packing plants. The bacon was not pumped as were the other cuts of meat, but in the curing solution it gained practically the same percentage in weight. One very noticeable feature about the oily meat was that it did not gain in cure like the firm and soft. In fact, the firm meat gained more than twice as much as the oily while in cure, both at Fort Worth and East St. Louis. This variation, however, should be kept in mind and compared with the difference in losses in smoke and during the retaining period.

Usually a heavy gain in cure is followed by a correspondingly heavy loss in smoke and during retaining period.

The combined results show the percentage gain as follows: Oily, 4.43 per cent; soft, 7.92 per cent; firm, 9.62 per cent.

TABLE 19.—*Soaking record of pickle-cured bellies (bacon).*

FORT WORTH.

	Lot No.	Weight of meat in soak (pounds).	Time meat soaked. Hours.	Time meat soaked. Minutes.	Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
Oily	1	458	2	12	463	80	5
	4	578	2	8	574	80	−4
	7	465	2	12	464	72	−1
	10	396	2	12	398	72	2
		1,897			1,899		2
Soft	2	512	2	12	507	80	−5
	5	495	2	8	495	80	0
	8	431	2	12	432	72	1
	11	466	2	12	462	72	−4
		1,904			1,896		−8
Firm	3	550	2	12	574	80	24
	6	512	2	8	514	80	2
	9	490	2	12	491	72	1
	12	503	2	12	505	72	2
		2,055			2,084		29

EAST ST. LOUIS.

	Lot No.	Weight of meat in soak (pounds).	Time meat soaked. Hours.	Time meat soaked. Minutes.	Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
Oily	1	534	1	45	539	70	5
	2	465	1	55	469	70	4
	3	457	1	55	462	70	5
	4	328	2		332	70	4
		1,784			1,802		18
Soft	2	481	1	55	483	70	2
Firm	1	598	1	45	600	70	2
	2	557	1	55	558	70	1
	3	476	1	55	477	70	1
	4	655	2		652	70	−3
		2,286			2,287		1

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS SOAKING RECORD ON BELLIES (BACON).

	Lot No.	Weight of meat in soak (pounds).	Hours.	Minutes.	Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain or loss in soak (pounds).
Oily:							
Fort Worth		1,897			1,899		2
St. Louis		1,784			1,802		18
		3,681			3,701		20
Soft:							
Fort Worth		1,904			1,896		−8
St. Louis		481			483		2
		2,385			2,379		−6
Firm:							
Fort Worth		2,055			2,084		29
St. Louis		2,286			2,287		1
		4,341			4,371		30

The meat varied considerably in soak. This was due to the fact that the meat was weighed each time out of a liquid which would naturally cause a variation.

TABLE 20.—*Smoke record of pickle-cured bellies (bacon).*

FORT WORTH.

	Lot No.	Weight in smoke (pounds).	Hours smoked.	Temperature of smoke house. Beginning (° F.).	Temperature of smoke house. Close (° F.).	Net weight of cooled meat (pounds).	Total loss in smoke. Pounds.	Total loss in smoke. Per cent.	Total loss from chilled fresh weight through smoke. Pounds.	Total loss from chilled fresh weight through smoke. Per cent.
Oily	1	463	28	85	125	400	63	13.61	44	9.91
	4	574	28	85	125	516	58	10.10	43	7.69
	7	464	26½	100	124	409	55	11.85	27	6.19
	10	398	26½	100	124	323	75	18.84	55	14.55
		1,899				1,648	251	13.22	169	9.30
Soft	2	507	28	85	125	430	77	15.19	40	8.51
	5	495	28	85	125	428	67	13.54	38	8.15
	8	432	26½	100	124	364	68	15.74	35	8.77
	11	462	26½	100	124	384	78	16.88	48	11.11
		1,896				1,606	290	15.30	161	9.11
Firm	3	574	28	85	125	472	102	17.77	29	5.79
	6	514	28	85	125	436	78	15.18	40	8.40
	9	491	26½	100	124	417	74	15.07	25	5.66
	12	505	26½	100	124	424	81	16.04	34	7.42
		2,084				1,749	335	16.07	128	6.82

EAST ST. LOUIS.

	Lot No.	Weight in smoke (pounds).	Hours smoked.	Beginning (° F.).	Close (° F.).	Net weight of cooled meat (pounds).	Pounds.	Per cent.	Pounds.	Per cent.
Oily	1	539	34½	76	63	478	61	11.32	46	8.78
	2	469	36	62	74	404	65	13.86	35	7.97
	3	462	34½	82	68	398	64	13.85	31	7.23
	4	332	32½	72	70	285	47	14.16	31	9.81
		1,802				1,565	237	13.15	143	8.37
Soft	2	483	36	62	74	411	72	14.91	32	7.22
Firm	1	600	34½	76	63	520	80	13.33	30	5.45
	2	558	36	62	74	486	72	12.90	23	4.52
	3	477	34½	82	68	402	75	15.72	37	8.43
	4	652	32½	72	70	584	68	10.43	1	.17
		2,287				1,992	295	12.90	91	4.37

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS SMOKE RECORDS ON PICKLE-CURED BELLIES (BACON).

	Lot No.	Weight in smoke (pounds).	Hours smoked.	Beginning (° F.).	Close (° F.).	Net weight of cooled meat (pounds).	Pounds.	Per cent.	Pounds.	Per cent.
Oily:										
Fort Worth		1,899				1,648	251	13.22	169	9.30
St. Louis		1,802				1,565	237	13.15	143	8.37
		3,701				3,213	488	13.19	312	8.85
Soft:										
Fort Worth		1,896				1,606	290	15.30	161	9.11
St. Louis		483				411	72	14.91	32	7.22
		2,379				2,017	362	15.22	193	8.73
Firm:										
Fort Worth		2,084				1,749	335	16.07	128	6.82
St. Louis		2,287				1,992	295	12.90	91	4.37
		4,371				3,741	630	14.41	219	5.53

In the Fort Worth tests lots 1 to 6 were held in the smoke 28 hours at a temperature ranging from 85° to 125° F., while lots 7 to 12 were smoked 26½ hours at a temperature ranging between 100° and 124° F.

The percentage shrinkage in smoke of the total amount of each kind of meat in the Fort Worth tests was: Oily, 13.22 per cent; soft, 15.30 per cent; firm, 16.07 per cent. This shows that the firm bellies (bacon) shrunk 2.85 per cent more than oily and 0.77 per cent more than the soft.

The same kind of meat cured in a similar manner in St. Louis was smoked from 32 to 36 hours at approximately the same temperature and showed a shrinkage of: Oily, 13.15 per cent; soft, 14.91 per cent; firm 12.90 per cent. In these tests the firm lost 0.25 per cent less than the oily and 2.01 per cent less than the soft.

The combined results of Fort Worth and St. Louis tests while in smoke show that oily meat lost 1.22 per cent less than firm and 2.03 per cent less than soft. However, the loss from chilled weight through smoke shows that the firm meat lost 3.32 per cent less than oily and 3.20 per cent less than soft.

TABLE 21.—*Retaining record of pickle-cured bellies (bacon).*

FORT WORTH.

	Lot No.	Weight cooled smoked meat (lbs.).	Weight of meat 24 hours after smoked (lbs.).	Net weight at end of— 6 days (lbs.).	Net weight at end of— 18 days (lbs.).	Loss during retaining period. Pounds.	Loss during retaining period. Per cent.	Green weight through retaining period. Total loss. Pounds.	Green weight through retaining period. Total loss. Per cent.	Green weight through retaining period. Per cent yield.
Oily	1	400	[1] 394	376	360	40	10.00	84	18.92	81.08
	4	516	[1] 513	494	480	36	6.98	79	14.13	85.87
	7	409	402	393	375	34	8.31	61	13.99	86.01
	[2] 10	....	....	....	....	....	....	....	....	....
		1,325	1,309	1,263	1,215	110	8.30	224	15.56	84.44
Soft	2	430	[1] 423	403	385	45	10.47	85	18.09	81.91
	5	428	[1] 424	408	392	36	8.41	74	15.88	84.12
	8	364	352	337	310	54	14.84	89	22.31	77.69
	11	384	375	361	334	50	13.02	98	22.69	77.31
		1,606	1,574	1,509	1,421	185	11.52	346	19.58	80.42
Firm	3	472	[1] 468	445	426	46	9.75	75	14.97	85.03
	6	436	[1] 432	408	388	48	11.01	88	18.49	81.51
	9	417	407	395	366	51	12.23	76	17.19	82.81
	12	424	411	395	366	58	13.68	92	20.09	79.91
		1,749	1,718	1,643	1,546	203	11.61	331	17.63	82.37

EAST ST. LOUIS.

	Lot No.	Weight cooled smoked meat (lbs.).	Weight of meat 24 hours after smoked (lbs.).	Net weight at end of— 6 days (lbs.).	Net weight at end of— 18 days (lbs.).	Loss during retaining period. Pounds.	Loss during retaining period. Per cent.	Green weight through retaining period. Total loss. Pounds.	Green weight through retaining period. Total loss. Per cent.	Green weight through retaining period. Per cent yield.
Oily	1	478	475	469	[3] 445	33	6.90	79	15.08	84.92
	2	404	399	384	[3] 367	37	9.16	72	16.40	83.60
	3	398	391	382	[3] 364	34	8.54	65	15.15	84.85
	4	285	279	268	[3] 254	31	10.88	62	19.62	80.38
		1,565	1,544	1,503	[3] 1,430	135	8.63	278	16.28	83.72
Soft	2	411	405	386	[3] 364	47	11.44	79	17.83	82.17
Firm	1	520	514	502	[3] 471	49	9.42	79	14.36	85.64
	2	486	478	460	[3] 439	47	9.67	70	13.75	86.25
	3	402	392	378	[3] 354	48	11.94	85	19.36	80.64
	4	584	574	551	[3] 521	63	10.79	64	10.94	89.06
		1,992	1,958	1,891	[3] 1,785	207	10.39	298	14.31	85.69

[1] 36 hours.
[2] 5 pieces were taken out by mistake, therefore lot 10 is not considered in retaining period record.
[3] 21 days.

TABLE 21.—*Retaining record of pickle-cured bellies (bacon)*—Continued.

COMBINED RESULTS OF FORT WORTH AND EAST ST. LOUIS RETAINING RECORDS ON PICKLE-CURED BELLIES (BACON).

	Lot No.	Weight cooled smoked meat (lbs.).	Weight of meat 24 hours after smoked (lbs.).	Net weight at end of— 6 days (lbs.).	Net weight at end of— 18 days (lbs.).	Loss during retaining period. Pounds.	Loss during retaining period. Per cent.	Green weight through retaining period. Total loss. Pounds.	Green weight through retaining period. Total loss. Per cent.	Green weight through retaining period. Per cent yield.
Oily:										
Fort Worth	......	1,325	1,309	1,263	1,215	110	8.30	224	15.56	84.44
St. Louis	......	1,565	1,544	1,503	1,430	135	8.63	278	16.28	83.72
		2,890	2,853	2,766	2,645	245	8.48	502	15.95	84.05
Soft:										
Fort Worth	......	1,606	1,574	1,509	1,421	185	11.52	346	19.58	80.42
St. Louis	......	411	405	386	364	47	11.44	79	17.83	82.17
		2,017	1,979	1,895	1,785	232	11.50	425	19.23	80.77
Firm:										
Fort Worth	......	1,749	1,718	1,643	1,546	203	11.61	331	17.63	82.37
St. Louis	......	1,992	1,958	1,891	1,785	207	10.39	298	14.31	85.69
		3,741	3,676	3,534	3,331	410	10.96	629	15.88	84.12

The combined results show that during the retaining period the oily meat shrank 2.48 per cent less than firm and 3.12 per cent less than soft.

The total shrinkage from chilled weight through all the processes to the end of the retaining period was: Oily, 15.96 per cent; soft, 19.23 per cent; firm, 15.88 per cent; or the oily meat showed a shrinkage of 0.07 per cent and the soft 3.35 per cent more than firm. Although there was a very great difference in the weight of the lots of oily and firm bacon out of cure, it was practically equalized at the end of the retaining period.

TABLE 22.—*Pumping record of dry salt cured bellies (sides), Fort Worth.*

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Gain by pumping. Pounds.	Gain by pumping. Per cent.
Oily	13	850	882	32	3.76
	16	707	728	21	2.97
	19	885	916	31	3.50
	22	650	677	27	4.15
		3,092	3,203	111	3.59
Soft	14	1,000	1,033	33	3.30
	17	778	805	27	3.47
	20	795	820	25	3.14
	23	685	709	24	3.50
		3,258	3,367	109	3.35
Firm	15	810	831	21	2.59
	18	840	868	28	3.33
	21	872	901	29	3.33
	24	900	920	20	2.22
		3,422	3,520	98	2.86

TABLE 23.—*Curing record of dry salt cured bellies (sides), Fort Worth.*

	Lot No.	Weight in cure (pounds).	Number of days in cure.	Swept weight (pounds).	Gain from chilled weight through cure.	
					Pounds.	Per cent.
Oily	13	882	31	852	2	0.24
	16	728	30	663	−44	−6.22
	19	916	33	877	−8	−.90
	22	677	32	622	−28	−4.31
		3,203	....	3,014	−78	−2.52
Soft	14	1,033	31	970	−30	−3.00
	17	805	30	740	−38	−4.88
	20	820	33	759	−36	−4.53
	23	709	32	654	−31	−4.53
		3,367	....	3,123	−135	−4.14
Firm	15	831	31	768	−42	−5.19
	18	868	30	856	16	1.90
	21	901	33	833	−39	−4.47
	24	920	32	905	5	.56
		3,520	....	3,362	−60	−1.75

DRY-SALT BELLIES.

Some of the bellies (side meat) were cured by the dry-salt method, because a large percentage of such meat is too large to be pickle cured and used for breakfast bacon, hence it was desirable to obtain data on the meat cured by the dry-salt process. The bellies from 300 hogs were divided into oily, soft, and firm and taken through cure, smoke, and retaining period together. This cut did not increase by pumping as much as the hams but the different grades did increase in about the same relative percentage. There was a noticeable difference between the swept weight of the dry-salt bellies and the cured weight of the pickled hams and bellies, which shows that meat pickle cured gains in weight, but meat cured in dry salt loses weight. In all lots except lots 13, 18, and 24, a loss in weight was recorded. It was also noted that the loss in the lots of soft meat was much greater and more uniform than in either the oily or firm.

From the chilled weight through the cure a loss was sustained as follows: Oily, 2.52 per cent; soft, 4.14 per cent; firm, 1.75 per cent.

TABLE 24.—*Soaking record of dry salt cured bellies (sides), Fort Worth.*

	Lot No.	Weight of meat in soak (pounds).	Time meat soaked.		Net weight of drained meat out of soak (pounds).	Temperature of water (° F.).	Gain in soak (pounds).
			Hours.	Minutes.			
Oily	13	852	2	35	850	75	−2
	16	663	1	....	676	75	13
	19	877	2	45	874	76	−3
	22	622	1	....	630	76	8
		3,014	....	....	3,030	....	16
Soft	14	970	2	35	977	75	7
	17	740	1	....	753	75	13
	20	759	2	45	768	76	9
	23	654	1	....	659	76	5
		3,123	....	....	3,157	....	34
Firm	15	768	2	35	780	75	12
	18	856	1	....	859	75	3
	21	833	2	45	843	76	10
	24	905	1	....	914	76	9
		3,362	....	....	3,396	....	34

TABLE 25.—*Smoke record of dry salt cured bellies (sides), Fort Worth.*

	Lot No.	Weight in smoke (lbs.).	Hours smoked.	Temperature of smokehouse at— Beginning (° F.).	Temperature of smokehouse at— Close (° F.).	Net weight of cooled meat (lbs.).	Total loss in smoke. Pounds.	Total loss in smoke. Per cent.	Total loss from chilled fresh weight through smoke. Pounds.	Total loss from chilled fresh weight through smoke. Per cent.
Oily	13	850	24	90	128	785	65	7.65	65	7.65
	16	676	24	90	128	609	67	9.91	98	13.86
	19	874	19	82	132	816	58	6.64	69	7.80
	22	630	19	82	132	569	61	9.68	81	12.46
		3,030	....	....	....	2,779	251	8.28	313	10.12
Soft	14	977	24	90	128	897	80	8.19	103	10.30
	17	753	24	90	128	680	73	9.69	98	12.60
	20	768	19	82	132	695	73	9.51	100	12.58
	23	659	19	82	132	594	65	9.86	91	13.28
		3,157	....	....	....	2,866	291	9.22	392	12.03
Firm	15	780	24	90	128	711	69	8.85	99	12.22
	18	859	24	90	128	786	73	8.50	54	6.43
	21	843	19	82	132	766	77	9.13	106	12.16
	24	914	19	82	132	841	73	7.99	16	1.78
		3,396	....	....	....	3,104	292	8.60	275	8.04

TABLE 26.—*Retaining record of dry salt cured bellies (sides), Fort Worth.*

	Lot No.	Weight cooled smoked meat (lbs.).	Weight of meat 24 hours after smoked (lbs.).	Net weight of meat at end of— 6 days (lbs.).	Net weight of meat at end of— 19 days (lbs.).	Loss during retaining period. Pounds.	Loss during retaining period. Per cent.	Fresh chilled weight through retaining period. Pounds loss.	Fresh chilled weight through retaining period. Per cent loss.	Fresh chilled weight through retaining period. Per cent yield.
Oily	13	785	781	764	734	51	6.50	116	13.65	86.35
	16	609	603	584	555	54	8.87	152	21.50	78.50
	19	816	812	795	770	46	5.64	115	12.99	87.01
	22	569	563	548	524	45	7.91	126	19.38	80.62
		2,779	2,759	2,691	2,583	196	7.05	509	16.46	83.54
Soft	14	897	893	869	831	66	7.36	169	16.90	83.10
	17	680	673	655	624	56	8.24	154	19.79	80.21
	20	695	692	671	644	51	7.34	151	18.99	81.01
	23	594	587	555	543	51	8.59	142	20.73	79.27
		2,866	2,845	2,750	2,642	224	7.82	616	18.91	81.09
Firm	15	711	705	689	658	53	7.45	152	18.77	81.23
	18	786	779	764	732	54	6.87	108	12.86	87.14
	21	766	759	738	708	58	7.57	164	18.81	81.19
	24	841	835	813	789	52	6.18	111	12.33	87.67
		3,104	3,078	3,004	2,887	217	6.99	535	15.63	84.37

The loss in smoke for the different kinds of meat was: Oily, 8.28 per cent; soft, 9.22 per cent; firm, 8.6 per cent. This shows that firm meat shrank 0.32 per cent and soft 0.94 per cent more than oily.

The percentage loss and resultant yield from chilled weight through the cure, smoke, and retaining period were as follows: Oily, 16.46 per cent; soft, 18.91 per cent; firm, 15.63 per cent. This shows that firm bellies cured by the dry-salt method and retained 19 days lost 0.83 per cent of the total weight less than oily and 2.45 per cent less than soft.

TABLE 27.—*Pumping record of dry-salt cured New Orleans shoulders, Fort Worth.*

	Lot No.	Chilled fresh weight (pounds).	Pumped weight (pounds).	Gain by pumping.	
				Pounds.	Per cent.
ily	4	429	457	28	6.53
	7	358	383	25	6.98
	10	381	418	37	9.71
	13	576	614	38	6.60
	16	580	615	35	6.03
	19	530	560	30	5.66
	22	511	544	33	6.46
		3,365	3,591	226	6.72
ft	5	391	420	29	7.42
	8	396	420	24	6.06
	11	419	453	34	8.11
	14	670	700	30	4.48
	17	621	655	34	5.48
	20	560	582	22	3.93
	23	580	604	24	4.14
		3,637	3,834	197	5.42
rm	6	397	414	17	4.28
	9	379	394	15	3.96
	12	398	426	28	7.04
	15	595	616	21	3.53
	18	513	538	25	4.87
	21	615	642	27	4.39
	24	630	658	28	4.44
		3,527	3,688	161	4.56

TABLE 28.—*Curing record of dry salt cured New Orleans shoulders, Fort Worth.*

	Lot No.	Weight in cure (pounds).	Number of days in cure.	Swept weight (pounds).	Gain or loss from chilled weight through cure.	
					Pounds.	Per cent.
y	4	457	62	420	−9	−2.10
	7	383	61	356	−2	−.56
	10	418	60	360	−21	−5.51
	13	614	60	572	−4	−.69
	16	615	59	558	−22	−3.79
	19	560	62	525	−5	−.94
	22	544	61	502	−9	−1.76
		3,591	....	3,293	−72	−2.14
t	5	420	62	380	−11	−2.81
	8	420	61	391	−5	−1.26
	11	453	60	405	−14	−3.34
	14	700	60	668	−2	−.30
	17	655	59	599	−22	−3.54
	20	582	62	548	−12	−2.14
	23	604	61	567	−13	−2.24
		3,834	....	3,558	−79	−2.17
m	6	414	62	382	−15	−3.78
	9	394	61	382	+3	+.79
	12	426	60	389	−9	−2.26
	15	616	60	581	−14	−2.35
	18	538	59	533	+20	+3.90
	21	642	62	606	−9	−1.46
	24	658	61	650	+20	+3.17
		3,688	....	3,523	−4	−.11

All of the oily and soft lots of New Orleans shoulders cured by dry-salt method lost in weight while being cured, but three lots of the seven classed as firm gained in weight.

There was a great variation, however, between lots of meat of the same kind, which was probably due to the amount of salt that remained on the meat after being swept, because this wide variation occurred with all three grades of meat.

Since these lots of shoulders were neither smoked nor retained a definite period of time, the results are not comparable with the other cuts.

The shrinkage through cure from chilled weight was: Oily, 2.14 per cent; soft, 2.17 per cent; firm, 0.11 per cent.

MELTING POINTS AND IODINE NUMBERS.

The samples of kidney fat used for the melting-point and iodine-number determinations were taken from hogs as nearly representative of the lots as possible. With some of the lots samples were selected from the softest and firmest hogs in order to determine the melting points and iodine numbers of both extremes in the same lot.

The average of the melting points for oily was 34.50 for East St. Louis tests and 34.90 for Fort Worth tests, for soft 40.28, and for firm 42.65 for East St. Louis and 44.16 for Fort Worth. The iodine numbers used as checks correspond inversely to the melting points.

TABLE 29.—*Melting points and iodine-number determinations made from fats taken from hogs out of test lots at East St. Louis and Fort Worth.*

EAST ST. LOUIS TESTS.

Lot No.	Melting point.		Iodine number.	
	Oily.	Firm.	Oily.	Firm.
	°F.	°F.		
1	32.70	44.00	85.00	59.1
2	39.80	41.50	72.85	62.9
3	[1] 26.50	[1] 43.10	[1] 81.74	[1] 71.0
	[2] 39.00	[2] 42.00	[2] 69.81	[2] 63.[illegible]
Average	34.50	42.65	77.35	64.[illegible]

FORT WORTH TESTS.

Lot No.	Melting point.			Iodine number.		
	Oily.	Soft.	Firm.	Oily.	Soft.	Firm.
	°F.	°F.	°F.			
4-5-6	27.20	32.10	42.10	84.28	75.40	66.
7-8-9	32.00	37.00	46.50	75.90	75.39	58.
10-11-12	[1] 30.50	[1] 40.60	[1] 40.40	[1] 86.56	[1] 73.62	[1] 67.
	[2] 36.70	[2] 41.40	[2] 45.70	[2] 81.99	[2] 70.82	[2] 62.
13-14-15	[1] 26.60	[1] 38.00	[1] 40.60	[1] 84.79	[1] 74.12	[1] 67.
	[2] 30.00	[2] 42.00	[2] 45.70	[2] 81.23	[2] 63.97	[2] 61.
16-17-18	[1] 36.00	[1] 36.10	[1] 45.00	[1] 77.93	[1] 75.90	[1] 59.
	[2] 41.90	[2] 43.00	[2] 45.00	[2] 71.59	[2] 63.72	[2] 59.
19-20-21	[1] 38.70	[1] 44.00	[1] 44.90	[1] 74.63	[1] 68.03	[1] 59.
	[2] 38.10	[2] 44.00	[2] 43.40	[2] 74.12	[2] 62.45	[2] 61.
22-23-24	[1] 38.70	[1] 40.40	[1] 45.50	[1] 74.63	[1] 70.57	[1] 58.
	[2] 42.40	[2] 44.80	[2] 45.10	[2] 64.99	[2] 60.42	[2] 56.
Average	34.90	40.28	44.16	77.72	69.54	61.

[1] Softest carcasses of each lot. [2] Firmest carcasses of each lot.

The melting points of the lots follow consecutively across the page; i. e., lot 4 oily, lot 5 soft, and lot 6 firm, etc.

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ALFALFA ROOT STUDIES.

By Samuel Garver, *Assistant Agrostologist, Office of Forage-Crop Investigations, Bureau of Plant Industry.*

CONTENTS.

SCOPE OF THE STUDY.

Only within recent years have the crown and the root characters of alfalfa been extensively studied and their relation to environmental factors carefully considered. The physical reasons for an alfalfa plant being resistant to cold or drought remain much in doubt, but the studies of various investigators tend to substantiate the general belief that they may be associated with broad, deep-set crowns, well-developed rooting rhizomes, and numerous branch roots. The publicity that has been given to these particular features has created the rather general impression that there is a much greater difference in the crown and root characters of the hardy and nonhardy alfalfas than actually exists. Plants with pronounced taproots are generally well enough adapted to regions with relatively high mean temperatures, while plants with the more branching root systems are less subject to winterkilling and to injury by rodents or cultivation. The broad, deep-set crowns that are usually associated with the branching root system are popularly considered a decided advantage in cold re-

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gions because of the protection afforded to dormant or resting buds. However, artificial protection by means of straw has been found to reduce the mortality of nonhardy plants only slightly under severe winter conditions. This would seem to indicate that cold resistance is an inherent characteristic and is dependent only to a slight degree on the soil protection that is afforded the resting buds. It is the purpose of this bulletin to present data showing more definitely the root characteristics assumed by representative varieties of alfalfa under stated field conditions for the relation they may have in the adaptation to environmental conditions. The descriptions of root systems contained herein are of the well-known varieties of alfalfa grown at the Redfield Field Station in South Dakota, under conditions which are probably quite representative of a considerable area of the northern Great Plains. It is recognized that with a different soil, climate, and method of culture, variations may occur, but it is believed that the general conclusions reached in this bulletin would be unchanged. A statement of the conditions under which the plants were grown is deemed desirable and is included with the other data presented.

FACTORS TENDING TO PRODUCE MODIFICATIONS OF ROOT GROWTH.

Root growth is influenced principally by soil, climate, cultural treatment, and injuries, and to a lesser degree by many other factors. Alfalfa is found growing under conditions of moisture from heavy to light precipitation; on soil types ranging from stiff, heavy clay to almost pure sand; and at altitudes from below sea level to 13,000 feet or more above sea level. Many of the alfalfas that have been introduced into the United States have been grown in different countries hundreds and possibly thousands of years within comparatively small areas and under peculiar soil and climatic conditions. It is hardly to be expected, therefore, that any one location can be found that will provide optimum conditions for the development of the root systems of all the different alfalfas.

SOIL CONDITIONS.

Root development is influenced by distribution of plant food, soil moisture, soil texture, water table, and hardpan or other hard material. Unusual soil formations in which there is a peculiar distribution of plant food may cause modifications in root growth, because roots have a tendency to remain and develop in the areas of the most favorable conditions of plant food. A number of experiments have been reported showing the influence of such plant-food distribution on root development.

While alfalfa roots are ordinarily able to penetrate compact soil strata, their ability to do so is modified to a considerable degree by moisture conditions. A soil layer may become so hardened by drought that the roots are unable to go through it, but such a condition may be alleviated by the presence of only a small quantity of moisture as a result of opportune rainfall. Compact soil appears to cause greater branching and less pronounced taproots, while the open or porous soils tend to produce long, slender taproots with few branches. The varied development of root systems due to differences in soil texture was noted in seedlings in similar kinds of alfalfa examined at Redfield, S. Dak., and Arlington Farm, Va., in 1916. The seedlings at Redfield showed pronounced taproots and few branches, while those examined at Arlington showed indistinct taproots and a mass of fibrous roots. Roots often terminate or else are deflected from their natural course by very hard material, such as hardpan or stone. On land where the water table is near the surface, the water will act as a barrier to deeper root growth. On irrigated lands root growth is influenced by the time and quantity of water applied.

CLIMATIC CONDITIONS.

The form and development of the root system is doubtless influenced, to some extent, by the weather conditions that immediately follow seeding. It has been found that alfalfa roots make very rapid early growth, especially at two to three months of age, and it is probably true that the form of the root system is most influenced within this period. Under north-temperate dry-land conditions, young plants from sowings made in early spring or late summer, are generally subject to a long period of cool and moist weather, while late-spring or early-summer sowings have a long period of relatively warm and dry weather in which to make their early growth. No data are available showing the exact effect of these conditions on the growth of the young plant, but they are doubtless of considerable importance.

CULTURAL FACTORS.

The application of stable manure or commercial fertilizers usually increases root growth. Inoculation with nitrogen-fixing bacteria where these are not already present in the soil also results in a larger root system. That root development is affected by close grazing or frequent cuttings was indicated by a test conducted at Redfield in 1916. A broadcast plat of alfalfa that was seeded August 12, 1915, was selected to determine the influence of frequency of clipping on root growth. This plat had an almost perfect stand, was free from weeds, and had not previously been harvested either for hay or

seed. One portion of the plat was harvested 3 times during the season, another 7 times, and the remaining portion 18 times. The result of the different treatments on the vitality of the plants was shown in the mortality that occurred the following winter. (Table 1.)

The plat harvested 3 times was clipped with a mowing machine, while the plats harvested 7 and 18 times during the season were clipped with a lawn mower. The harvested material was removed from the plats in all cases.

FIG. 1.—Alfalfa roots from a plat clipped three times during the second season.

TABLE 1.—*Effect of frequency of clipping on the vitality of alfalfa plants at Redfield, S. Dak., in 1916 and 1917.*

Treatment during the season of 1916.	Stand (per cent).		Mortality, winter of 1916–17 (per cent).
	1916	1917	
Clipped 3 times during season	100	83	17
Clipped when 6 inches tall, 7 times during season	100	8	92
Clipped 18 times during season	100	1+	98+

The data given in Table 1 show that the plants from the plats clipped 7 and 18 times were so weakened in vitality by the frequent clippings that they suffered almost complete mortality the following winter. Although considerable winterkilling occurred in the plat harvested three times for hay, a satisfactory stand remained.

In October, 1916, at the close of the period of treatment, 12 plants were removed from each of the plats and the root systems photographed. The plants in each case were taken consecutively from representative areas. The plants from the plat harvested 3 times during the season showed a much larger and stronger root growth

than plants from the plats harvested 7 and 18 times. This experiment showed that root development of alfalfa is retarded and vitality reduced by frequent clipping. It is probable that close grazing would have much the same effect. (Figs. 1, 2, and 3.)

Thick seedings which result in crowding, especially during the early life of the plant, tend to produce small crowns and root systems. To determine the relations between space available to the plant and the diameter of the taproot, measurements were made on plants that were removed from the nurseries at Redfield in August and October, 1919. The results are given in Table 2.

FIG. 2.—Alfalfa roots from a plat clipped seven times during the second season. The alfalfa was clipped each time when 6 inches tall.

TABLE 2.—*Relation of diameter of the taproots of alfalfa plants to thickness of stand in nursery plantings at Redfield, S. Dak., in 1919.*

Average length of row from which 25 consecutive plants were removed.[1]	Plants considered.		Average diameter of each taproot[2] (millimeters).	Average length of row from which 25 consecutive plants were removed.[1]	Plants considered.		Average diameter of each taproot[2] (millimeters).
	Average distance apart (inches).	Number.			Average distance apart (inches).	Number.	
24 inches	0.96	100	9.588	41.7 inches	1.66	100	11.334
28 inches	1.12	100	9.715	48 inches	1.92	50	12.065
30.4 inches	1.21	175	10.259	64 inches	2.56	25	12.700

[1] All rows 36 inches apart. [2] Measurements made 1 inch below the base of the crown.

It is clearly shown in Table 2 that there is an increase in diameter of taproot with the increase in the space between plants, indicating at least in similar varieties of alfalfa that the size attained by the taproot is determined more by the space the plant occupies than by its varietal tendencies. While this is true of the taproot the branch-root development seems to depend more upon the variety than upon the number of plants that occupy a given space.

ABNORMALITIES DUE TO INJURIES.

Abnormalities may be the result of injuries due to alternate freezing and thawing, to cultural treatment, rodents, insects, or disease. Only the more evident of these will be considered in this connection.

The breaking of roots due to soil heaving is a common occurrence in regions of considerable precipitation and subject to rather suddenly alternating temperatures above and below freezing. The breaking of taproots near the surface in plants with few branch roots may prove fatal, but where there is considerable branching of the taproot near the crown the plant will ordinarily survive, being supported by some of the branch roots that have not been broken. Root injury caused by the heaving of the soil has proved to be a serious factor in the humid sections of the northern United States. but does not commonly occur in the Great Plains.

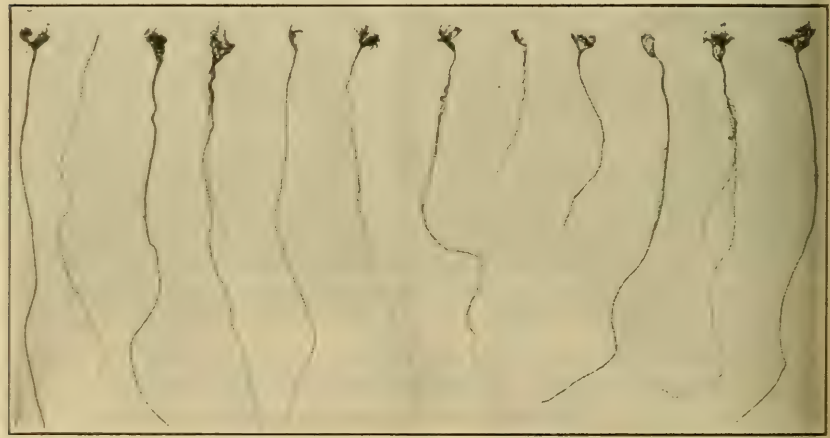

FIG. 3.—Alfalfa roots from a plat clipped 18 times during the second season.

Transplanted plants develop many more branches than where they continue growing under normal conditions. This is because the tap root is generally severed a few inches below the crown, which results in the development of an abnormal number of branch roots. Plants vary in their ability to produce these lateral roots. A very good example of a plant possessing this characteristic to a considerable degree is shown in Figure 4. Six consecutive plants of the same variety of alfalfa grown from seed were removed from the field and the root systems photographed. (Cf. Fig. 15.) Only one of the plants from seed approached in any way, or would in time approach, the type of a reset plant.

Where plants are grown in pots the roots are so closely confined that they assume a spiral form and when transplanted to the field continue to develop abnormally. The root system instead of spread

ing through the soil remains restricted, and after growing in the field for several months the plants can be easily pulled out. The effect of transferring seedlings of Grimm alfalfa, 40 days old, to flowerpots for a period of 39 days is shown in Figure 5. These plants were taken from the drilled row on June 24, 1920, and put in small pots which were set in the ground. On August 2, 1920, the flowerpots were broken, so that the roots were permitted to spread through the soil. The plants were removed from the field

FIG. 4.—Reset plant of yellow-flowered alfalfa (*Medicago falcata*), showing the very extensively branched root system.

and photographed on October 19. Such treatment appeared to produce distortions of the roots and to promote the growth of many more branches. The effect of limited space for root development on young plants is again illustrated in Figure 6. In this case Grimm alfalfa was sown in small pots on June 24, 1920, and the pots set in the ground. The young seedlings were thinned to one plant to each pot and permitted to grow in this limited area until August 2, when the pots were broken, permitting the roots to spread through the soil. Although the growth of these plants was less than that of the older seedlings (Fig. 5) which were transplanted from the field to the pots, nevertheless the roots showed the same tendencies toward

branching and distortion. It is, therefore, quite evident in studying transplanted plants—whether from pots to field or from field to field—that due consideration must be given to the effect of such treatment upon root development.

Cultivation modifies the normal root system by injuring or destroying a large number of the surface roots. The use of the disk harrow on alfalfa fields has been recommended frequently on the theory that by means of it soil moisture is conserved, weeds eliminated, and the stand thickened by splitting the crowns. Experiments generally have shown that such treatment is injurious in that it weakens or kills many of the plants.

FIG. 5.—Production of branch roots and distortions in Grimm alfalfa plants 166 days old. From the 49th to the 87th day the root systems were confined in small flower-pots.

In many localities alfalfa roots are subject to considerable injury by rodents, such as gophers and mice. When they sever the taproot very close to the crown, as frequently happens, there is no opportunity for the plant to develop side roots, and it soon dies. If the taproot is severed several inches below the crown, the plant often survives and throws out branch roots, behaving much as a transplanted plant does. At Highmore, S. Dak., in 1912 and 1913, several *Medicago falcata* plants had their main roots severed by gophers, yet these plants have continued to live, although much reduced in vitality. *Medicago sativa* plants failed to survive when the taproot was severed so near the crown. Malformations in roots may sometimes be caused by disease, the presence of which can only be determined by close examination.

VARIETIES STUDIED.

Field studies of the root systems of the more common commercial varieties or strains of alfalfa and of forms of the yellow-flowered species (*Medicago falcata*) have been conducted at the Redfield field station at various times between 1914 and 1920. The varieties and strains[1] taken into consideration include the Peruvian, Poona,[2] southern-grown common, northern-grown common, Turkestan, Grimm, and yellow flowered, and form the basis of the principal part of this study.

The Turkestan, Grimm, and yellow-flowered alfalfas passed through the four-season period from 1916 to 1919, inclusive, with

Fig. 6.—Distortions and the production of branch roots in Grimm alfalfa plants 117 days old. These plants were confined in small flowerpots during the first 39 days.

little thinning of stand. The southern-grown common had approximately 22.5 per cent mortality during the period, while the Peruvian and Poona were almost completely winterkilled the first winter. The root systems of 12 consecutive plants of each variety and strain were taken in October, 1916, and photographed. In May, 1917, after growing one season, 25, 75, or 100 plants of each variety and strain were removed consecutively for the purpose of making observations, measurements, and estimates of the more important root characteristics. In August and October, 1919, after growing four seasons, additional data were obtained by taking sets of the same

[1] For definitions and a classification of varieties and strains of alfalfa, see Farmers' Bulletin 757.

[2] An introduction from Poona, India.

number of plants of the same alfalfas. The roots taken in October, 1916, and May, 1917, were from the central portion of 8-rod rows; the roots taken in August, 1919, were from the north ends of the rows and those taken in October, 1919, were from the south ends. Data, unless otherwise stated, were obtained on the first 18 inches of root. This portion of the work was concluded in 1919. It was later found desirable to include data comparing southern-grown common and Grimm with plants of the same age of the prostrate and decumbent forms of pure *Medicago falcata*. In the fall of 1920, after growing six seasons, plants were removed from the nursery. No apparent mortality had occurred among the yellow-flowered plants from the time they were planted in May, 1915, to September, 1920. Only a 5 per cent mortality occurred in the Grimm variety, although some of the surviving plants showed winter injury. In the southern-grown common, 40 per cent of the plants had been killed or very seriously injured. All plants of *Medicago falcata* had pure yellow flowers and there were no evidences of hybridization.

CONDITIONS UNDER WHICH VARIETIES WERE GROWN.

Root studies were conducted from 1916 to 1919 upon varieties of alfalfa sown May 24, 1916, in drilled rows 36 inches apart and under similar soil conditions. The alfalfas studied in September, 1920, were sown in 42-inch rows in May, 1915. The only treatment to which these rows were subjected was clean cultivation throughout the season and the burning off of the dead stems in the early spring. The soil is fertile, well drained, and well supplied with organic matter and nitrogen-fixing organisms. In order to determine the character of the soil, a trench was opened in the alfalfa nursery in October, 1916, and samples taken at various depths and sent to the Bureau of Soils, United States Department of Agriculture, where a mechanical analysis and determination of calcium carbonate were made. The results obtained are shown in Table 3.

TABLE 3.—*Mechanical analyses and determination of calcium carbonate in representative soils at the Redfield Field Station, S. Dak.*

Depth from which soil sample was taken.[1]	Description.	Constituents (per cent).							
		Lime ($CaCO_3$).	Fine gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.10 mm.	Very fine sand, 0.10 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay, 0.005 to 0 mm.
0 to 1 foot	Silty clay loam	0.25	0	0.3	0.4	11.6	13.1	52.1	22.1
1 to 4 feet	Clay	13.63	0	.1	0	1.1	1.9	24.7	72.2
4 to 5 feet	Silt loam	11.45	.9	1.0	.4	1.0	2.2	81.4	13.2
5 to 8 feet	Clay	6.97	0	0	0	.2	.3	33.5	66.0
8 to 10 feet	do	6.31	0	0	0	1.2	1.0	21.6	76.1

[1] Samples, as listed in the table, are averages for the depths stated.

The analyses showed a high percentage of lime, especially at a depth of 1 to 5 feet. The surface foot is a fairly open black silty clay loam. At a depth of 1 to 4 feet it consists of a high percentage of fine soil particles and is fairly compact. A silty loam of a soft, shaly nature occurs at a depth of 4 to 5 feet. From 5 to 10 feet the soil is a clay that is apparently easily penetrated by alfalfa roots.

Investigations indicate that the type of root growth is pretty definitely determined during the first few months, and for this reason a summary of temperature and precipitation records is presented as indicating in a general way the moisture available to the plant (Table 4).

TABLE 4.—*Summary of precipitation and temperature records at Redfield, S. Dak., from April, 1916, to March, 1917.*

Items of comparison.	Growing season, 1916.					Fall conditions, 1916.			Winter conditions, 1916–17.			
	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Total precipitation, inches	1.11	5.13	3.56	2.01	5.19	1.42	0.55	T	2.13	2.38	0.8	2.25
Departure from normal, inches	−.65	+2.22	+.82	−.95	+1.97	−.45	−.8	−0.4	+1.75	+2.09	+.37	+1.6
Average temperature, °F	43	55.6	62.4	78.8	70	58.2	43.8	30.9	7.8	5	4	23.9
Departure from normal, °F	−1.7	0	−3.2	+8.5	.6	−1	3	−.5	−9.9	−7	−8.4	−5.3
Total precipitation, inches	17.00					1.97			7.55			
Departure from normal, inches	+3.41					−1.65			+5.81			

These data show that the season was favorable for alfalfa growth. There was an abundance of rainfall and cool weather in early spring and as late as early July. Drought then became gradually more pronounced, and unusually high temperatures prevailed until the middle of August, when rains occurred, resulting in late summer and fall growth. It would appear that conditions were favorable for a well-established root system in early spring and during the summer.

DIFFICULTIES ENCOUNTERED IN GETTING COMPARABLE DATA.

The chief difficulty encountered in obtaining comparable data on root systems in old fields of the less hardy alfalfa varieties and strains under the more severe environmental conditions is in making proper allowance for the doubtless accentuated growth of the surviving plants. The more susceptible plants having been winter-killed, the data obtained are from the more hardy individuals that have been given more room, permitting a greater root growth. In these studies at Redfield it was recognized that this thinning of stands and its effect on root growth was a factor that must be taken

into consideration. In order to obtain a more thorough conception of its effect data were obtained on the extent of the mortality between 1917 and 1919, measurements being also made showing the increase in root diameter during this period. The data obtained showed rather conclusively that the dying of the plants in the field resulted in a larger taproot growth of the survivors and that the roots of the plants surviving were of a more branching type. A decrease in the stands of the less hardy alfalfas, during a growth of four seasons, amounted to as much as 22.5 per cent and was found to be accompanied by an increase in root diameter of 74.9 per cent.

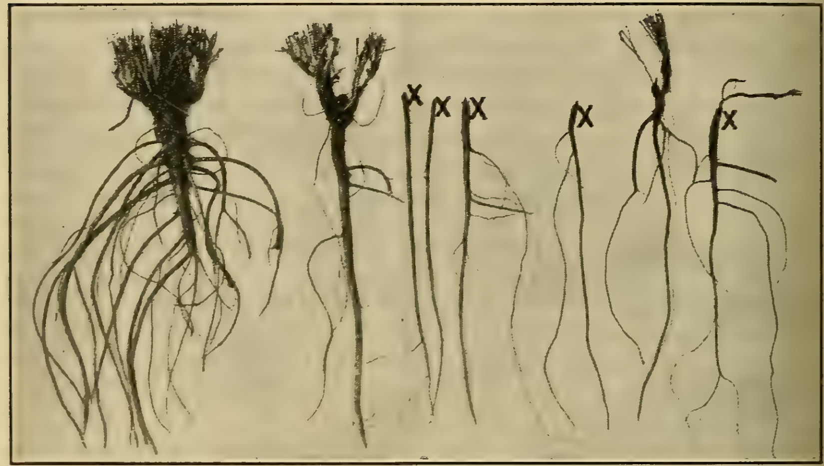

FIG. 7.—Root systems of plants of southern-grown common alfalfa (*Medicago sativa*), indicating the large percentage of mortality occurring in this strain during the 6-year period from 1915 to 1920, inclusive. Roots marked × represent dead plants.

while with hardy alfalfas where there was almost no mortality the increase was appreciably less. This amounted to 64.2 per cent in Turkestan alfalfa and to 55.8 per cent in the Grimm variety. As data which will be presented later show no distinguishing differences between these varieties and strains in the size of the taproot, it is apparent that the greater increase in root diameter of the nonhardy alfalfa was probably due to the thinning of the stands, which not only eliminated the small plants but permitted a greater root growth of the surviving plants. (Figs. 7, 8, and 9.)

CHARACTERISTIC ROOT SYSTEMS OF SOME OF THE WELL-KNOWN VARIETIES OF ALFALFA.

An attempt is here made to describe and compare in a simple way and to illustrate with photographs the types of root systems that are characteristic of the best-known varieties of alfalfa. By so doing it is hoped to convey a better idea of their points of similarity and their differences than now appears to prevail.

NONHARDY ALFALFAS.

As the term indicates, the group of nonhardy alfalfas includes those varieties and strains that can be grown successfully only in regions having such a mild climate that little or no winterkilling occurs. The Peruvian alfalfa is the only well-known variety of this group in the United States, and the area to which it is adapted is limited to sections where the minimum temperature seldom falls below 10° F.

FIG. 8.—Root systems of plants of Grimm alfalfa, indicating considerable injury but only a small percentage of mortality in this variety during the 6-year period from 1915 to 1920, inclusive. The root marked × represents a dead plant.

PERUVIAN ALFALFA.

As few plants of the Peruvian variety survive the winter at Redfield, it was necessary to make observations on roots of plants of one season's growth. This is a purple-flowered alfalfa having a narrow, upright crown, few crown branches, and only occasional rooting rhizomes. The taproots are very prominent, and branch roots are few, small, irregularly distributed, and seldom rebranched. Fibrous roots, which are generally more abundant near the surface in the hardier alfalfas, are sparse and uniformly distributed over the entire root system. With the exception of the Poona alfalfa, the Peruvian alfalfa made the smallest root growth in the first season of any of the alfalfas studied at Redfield. The differences between the root systems of this variety and other varieties and strains of one season's growth are well shown by comparing Figure 10 with Figures 11 to 14, inclusive.

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POONA ALFALFA.

In 1913 the United States Department of Agriculture received seed of a distinct variety of *Medicago sativa* from west-central India. This alfalfa, which has been given the name of Poona, from its source, has proved to be even less hardy than the Peruvian variety. Poona alfalfa seeded at Redfield in 1915 suffered complete mortality the following winter, while Peruvian seeded under the same conditions had a small percentage of survival. The variety is characterized by narrow, upright crowns, few crown branches, and very few, if any, rooting rhizomes. It differs from most other varieties in the almost entire absence of branch roots on the upper portion of the taproot. At a depth of 8 to 12 inches, however, branch roots are

FIG. 9.—Root systems of decumbent plants of yellow-flowered alfalfa (*Medicago falcata*). No winterkilling and very little injury occurred in this alfalfa during the 6-year period from 1915 to 1920, inclusive.

relatively profuse. Fibrous roots are sparse and rather uniformly distributed over the root system. The differences between roots of one season's growth of this and other varieties and strains are shown by a comparison of Figure 11 with Figures 10 and 12 to 14, inclusive.

COMMON ALFALFAS.

The common alfalfas include the purple-flowered strains generally grown throughout the western United States. It is believed that practically all of them have a common lineage, being descended from stock introduced into California during the early history of that State. For convenience they may be arbitrarily placed in two groups: Southern-grown common and northern-grown common.

SOUTHERN-GROWN COMMON ALFALFA.

Having comparatively small, upright crowns and pronounced taproots, southern-grown common alfalfa also has relatively few branch

roots, fibrous roots, and rooting rhizomes. The crowns are somewhat larger than in the less hardy varieties, such as Poona and Peruvian, but smaller than in Grimm and Turkestan. The taproot is prominent, grows vertically downward, and tapers slowly. In diameter there is no distinguishing difference between this variety, the Turkestan, and the hybrid alfalfas, as is shown in Table 5.

Fig. 10.—Root systems of Peruvian alfalfa plants, the growth of one season.

As a result of the greater mortality in southern-grown common alfalfa, each plant had more space than the ordinary varieties. It is probable that with the same amount of space the differences in root diameter would be somewhat greater than is shown in the table.

Table 5.—*Average diameter of taproots of different kinds of alfalfa at Redfield, S. Dak., in 1917, 1919, and 1920.*

[Studies in 1917 and 1919 made on 1916 seedings; in 1920, on 1915 seedings.]

Kind.	Number of plants observed, each date.	Measurements made within 1 inch of the crown.							
		Average root space per plant (inches).				Average diameter of taproots (mm.).			
		May, 1917.	August, 1919.	October, 1919.	September, 1920.	May, 1917.	August, 1919.	October, 1919.	September, 1920.
Southern-grown common	100	1.08	1.30	1.74	....	5.52	9.72	5.60	....
Turkestan	25	1.36	1.60	1.04	....	6.60	11.16	10.52	....
Grimm	75	1.49	1.30	1.56	....	6.84	9.94	11.25	....
Southern-grown common	32	....	....	....	2.12	....	....	....	[a] 11.56
Grimm	32	....	....	....	1.56	....	....	....	12.43
Decumbent yellow flowered	19	....	....	....	6.31	....	....	....	11.00
Prostrate yellow flowered	22	....	....	....	2.18	....	....	....	8.50

[a] The large root diameters in southern-grown common plants in 1919 may be accounted for by the high mortality occurring between 1916 and 1919, which probably left the larger and stronger ones.

Division of the taproot occurs less frequently than in the Grimm and Turkestan varieties.

Table 6 tends to show that branch roots in the southern-grown common alfalfa are perceptibly less abundant than in the Turkestan and Grimm. They are, however, relatively large, thus making the branching system appear somewhat more prominent (Table 7, column 3) than the number recorded would indicate.

FIG. 11.—Root systems of plants of Poona alfalfa (*Medicago sativa*), the growth of one season.

TABLE 6.—*Number of branch roots occurring in different kinds of alfalfa at Redfield, S. Dak., in 1917, 1919, and 1920.*

[Studies in 1917 and 1919 made on 1916 seedings; in 1920, on 1915 seedings.]

Kind.	Plants observed.		Counts of branch roots 2 mm. or more in diameter from crown to 18 inches below.							
			May, 1917; 1 season's growth.		August, 1919; 4 seasons' growth.		October, 1919; 4 seasons' growth.		September, 1920; 6 seasons' growth.	
	Number, each date.	Average distance apart (inches).	Mortality, 1916–17 (per cent).	Average branch roots per plant.	Mortality, 1916–19 (per cent).	Average branch roots per plant.	Mortality, 1916–19 (per cent).	Average branch roots per plant.	Mortality, 1916–19 (per cent).	Average branch roots per plant.
Southern-grown common	100	1.37	None.	2.15	13	3.52	32	3.68		
Turkestan	25	1.32	None.	3.88	None.	5.20	9	4.24		
Grimm	75	1.45	None.	4.33	5	4.34	4	3.96		
Southern-grown common	32	2.12							40	[1] 5.78
Grimm	32	1.56							5	5.93
Decumbent yellow flowered	19	6.31							None.	11.47
Prostrate yellow flowered	22	2.18							None.	6.90

[1] The large number of branch roots in southern-grown common alfalfa is probably due to extensive plant mortality between 1915 and 1920, which probably left the plants with the greater branch-root development

The angle which the branch roots form with the taproot is quite similar in all the alfalfas studied, with the exception of the yellow-flowered variety where this angle is somewhat greater. Fibrous roots, while more numerous than in Peruvian and Poona alfalfas, are relatively sparse and well distributed over the root system, differing in this respect from the hardier varieties. (Table 7, column 4.) Rooting rhizomes are fewer and not so well developed as in northern-grown common, Turkestan, or Grimm. (Fig. 12.)

FIG. 12.—Root systems of southern-grown common alfalfa plants, the growth of one season.

TABLE 7.—*Estimates of the prominence of the branch roots and the relative abundance of fibrous roots in different kinds of alfalfa at Redfield, S. Dak.*

Kind.	Number of plants considered.	Prominence of branch roots.	Relative abundance of fibrous roots.
Southern-grown common	300	[1] 85	[2] 85
Northern-grown common	75	92	92
Turkestan	75	96	97
Grimm	225	96	97
Decumbent yellow flowered	19	[3] 100	98
Prostrate yellow flowered	22	98	[4] 100

[1] Few branch roots; prominent taproots.
[2] Rather sparse.
[3] Branch roots numerous; taproot indistinct.
[4] Very abundant.

NORTHERN-GROWN COMMON ALFALFA.

In the United States the hardy strains of common alfalfa are largely the result of selective acclimatization, although in many cases the presence of a small percentage of *Medicago falcata* blood has contributed to the hardiness of these strains.

Most of the seed that is placed on the market is produced in Montana and the Black Hills region of South Dakota. The root systems of this alfalfa are fairly uniform and intermediate between the root system characteristic of southern-grown common alfalfa and that of the hardier varieties, such as Turkestan and Grimm. The taproot is quite distinct and branch roots are most prominent at 1½ to 4 inches below the crown. This is somewhat nearer the surface than is characteristic of the southern-grown strains and almost identical with the Turkestan and Grimm. In number and prominence of branch roots, the northern-grown common alfalfa exceeds the southern grown, but does not equal the Turkestan and Grimm. The distinguishing

FIG. 13.—Root systems of northern-grown common alfalfa plants, the growth of one season.

differences in these respects, however, are usually so slight that they can be noted only by examining many plants. (Fig. 13.)

TURKESTAN ALFALFA.

Strains of Turkestan[3] alfalfa have been under test for a number of years in the northern Great Plains region, and certain introductions have proved hardy and quite productive. They are characterized by broad, deep-set crowns and more numerous crown branches than the common and nonhardy alfalfas. The taproots are relatively shorter, more tapering, and less distinct than in common, Peruvian, and Poona. The diameter of the taproot somewhat exceeds that of the nonhardy alfalfas studied, but as measurements show, it is somewhat less in plants of one season's growth than in the Grimm alfalfa.

[3] The root systems of plants of Turkestan alfalfa studied at Redfield were from plats sown with seed that was the result of several seed generations in the northern Great Plains region. The original seed was of S. P. I. No. 991, which was collected under the direction of the U. S. Department of Agriculture at Tashkend, Turkestan, in 1898.

In plants of four season's growth the diameter of the taproot of Turkestan alfalfa is slightly greater than that of the Grimm. Branch roots are abundant and prominent, occurring in greatest profusion at 1½ to 4¼ inches below the crown. The average angle of divergence is greater than in any of the alfalfas studied except that of *Medicago falcata*. Fibrous roots are very abundant and most numerous within 6 inches of the surface. Well-developed rooting rhizomes are common. The Turkestan alfalfa differs from the nonhardy varieties in possessing decidedly larger numbers of branch roots and fibrous roots; but, as shown by the data presented in Tables 5, 6, and 7, the differences in the more pronounced root characters between this variety and Grimm are not sufficient to distinguish one from the other.

GRIMM ALFALFA.

Grimm alfalfa is the best-known variety of variegated alfalfa in the United States. It is a cross between *Medicago falcata* and *Medicago sativa* and was brought to Minnesota from Germany in 1858. It has been grown under rather severe conditions since that time, and as a result only the most hardy plants have survived. The plants studied at Redfield were of stock that had proved hardy and productive.[4] The root systems showed greater irregularity than other varieties studied, probably owing to the fact that this alfalfa is a hybrid.

In order to observe root development in considerable detail, a trench several feet in depth was dug along one of the nursery rows. Many of the taproots were found to divide, some near the surface and others at considerable depths. The branch roots diverged from the taproot at angles varying from 50° to 80° for about 12 inches, when most of them turned vertically downward, being only slightly deflected by a compact soil stratum at a depth of 3 to 4 feet.[5] At this point more than the normal amount of branching occurred. As the next 12 inches of soil was somewhat more friable, the roots seemed to experience no difficulty in penetrating it. Small channels occurred throughout the soil which contained either partially decomposed roots or showed evidence of having been root passages. Branch roots, although most abundant near the surface, were found all along the taproot. Small fibrous roots occurred over the entire root system, being especially numerous within 5 or 6 inches of the crown. In a few instances the fibrous roots were traced to a depth of 9 feet 4 inches, where they terminated in a rather dry clay stratum. The

[4] This seed (S. P. I. No. 29988) was harvested from a field 40 years old in Carver County, Minn. It was purchased by the Department of Agriculture from A. B. Lyman, of Excelsior, Minn., in February, 1911.

[5] Compare with data in Table 3.

area occupied by the roots of a single 3-year-old plant was estimated to be 3 feet in diameter and 10 feet deep.

Taproots of Grimm alfalfa taper more rapidly than those of less-hardy strains, but just below the crown there appears to be only a slight difference in the diameters of the taproots of the different varieties, as is shown in Table 5. In the number of branch roots the Grimm alfalfa exceeds the southern strains, as is indicated in Table 6. Grimm and Turkestan alfalfa show somewhat greater angles of divergence of the branch roots than southern-grown common, but the variations are hardly sufficient to constitute distinguishing characteristics. As is shown in Table 7 the Grimm alfalfa dif-

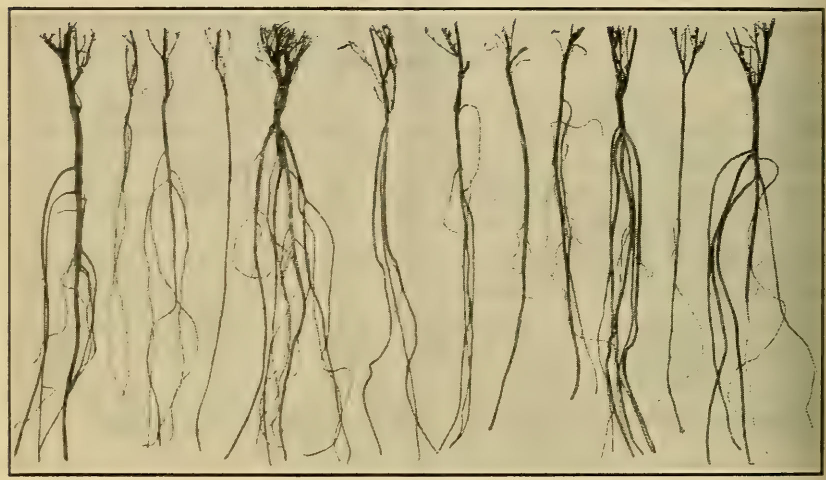

FIG. 14.—Root systems of Grimm alfalfa plants, the growth of one season.

fers from the less hardy varieties by having more numerous fibrous roots, which are most abundant within $5\frac{1}{4}$ inches of the crown. In the southern-grown strains the fibrous roots are relatively sparse and quite uniformly distributed over the root system. Rooting rhizomes are often well developed; but, in this respect, the Grimm alfalfa is not quite so marked as the yellow-flowered kind. (Figs. 14 and 15.)

The root systems of Grimm alfalfa and the strain of Turkestan alfalfa studied are so similar that even the closest examination will not serve to distinguish between them. The chief difference is the greater uniformity of the root systems in the Turkestan variety. It appears possible, however, to distinguish the southern-grown common alfalfa from either of these varieties by close study of the root systems of a large number of plants. This can not be done where only one or two are available for study.

YELLOW-FLOWERED ALFALFA.

While several introductions of yellow-flowered alfalfa (*Medicago falcata*) have been made since 1897, none of them is of commercial importance. As a whole, they are characterized by many branch roots, which taper so gradually that they are often as large at a distance of 2 or 3 feet as they are at the point of origin. They usually extend to a greater depth than the taproot—where it is present. Fibrous roots are abundant, especially near the surface. Crown branches and rhizomes are small and numerous. Based upon manner of growth, these alfalfas may be divided into three general classes: (1) Erect, with narrow crowns, upright stems, and root system, like *Medicago sativa;* (2) prostrate, with broad, deep-set crowns, prostrate stems, and a much-branched root system; and (3)

Fig. 15.—Root systems of plants of yellow-flowered alfalfa (*Medicago falcata*), the growth of two seasons.

decumbent, intermediate between Nos. 1 and 2 as to root system and general habit of growth. At Redfield the roots of the yellow-flowered alfalfa seldom reach a depth greater than 5 feet, while Grimm alfalfa, grown under similar conditions, attains a depth of 10 feet.[6]

Erect yellow-flowered alfalfa.[7]—The erect form of *Medicago falcata* is distinguished from the other types of the species by the shape of the crown and the prominence of the taproot, which is relatively small but quite as distinct as that of the Grimm alfalfa. The branch roots are more numerous, smaller, and more slowly tapering.

[6] Frank N. Meyer reports roots of large size growing in open sandy soils on the banks of the Tom River near Tomsk, Siberia. Some plants were found with roots fully 2 inches in diameter at the crown and more than 1 inch in diameter at a depth of 14 feet. A few of the roots were found to extend to a depth of 33 feet.

[7] S. P. I. No. 20721 (*Medicago falcata*), from Samara Province, Russia, as found wild. (See S. P. I. No. 20726.)

Figure 15 shows roots of one of the most upright, narrow-crowned forms of yellow-flowered alfalfa that has been introduced. Seven of these plants have distinct taproots and five show a decided branching tendency. The branch roots are put forth obliquely and form a somewhat greater angle with the taproot than is the case with Grimm and Turkestan. The crown is quite similar to that of the Grimm except that the crown branches and rhizomes are smaller and more numerous. Fibrous root are relatively abundant.

FIG. 16.—Root system of a prostrate yellow-flowered alfalfa plant, the growth of six seasons.

Prostrate yellow-flowere alfalfa.[8]—The prostrat yellow-flowered alfalfas ar characterized by very broa deep-set crowns, well-devel oped rhizomes, and dens root systems. Taproots ar either not apparent or ar very short and indistinc As shown in Table 6, branc roots are somewhat moı numerous than in *Medicag sativa.* The angle that th branch roots form with th taproot is somewhat greate than with purple-flowere and hybrid alfalfas. large percentage of th branch roots originate fro the rhizomes, thus sugges ing that the highly deve oped root system is at th expense of the taproot ar its branches. Rhizomes a longer and more branchir than in the common variegated alfalfas. Fibrous roots occur in considerable abundan in all parts of the root system. (Figs. 16 and 17.)

[8] The alfalfa considered is S. P. I. No. 20717 (*Medicago falcata*), from Kharkof Pr ince, southwestern Russia, a wild form.

Decumbent yellow-flowered alfalfa.[9]—The decumbent form of yellow-flowered alfalfa is intermediate between the two forms previously considered. The type is represented by S. P. I No. 33465. The taproots are indistinct, short and rapidly tapering and slightly smaller than the southern-grown common and Grimm varieties, as is shown in Table 5. This strain has the most extensive root system of all the alfalfas studied. The rhizome development is greater than any of the alfalfas except the prostrate yellow-flowered. Fibrous roots are relatively abundant. (Table 7, Figs. 9 and 18.)

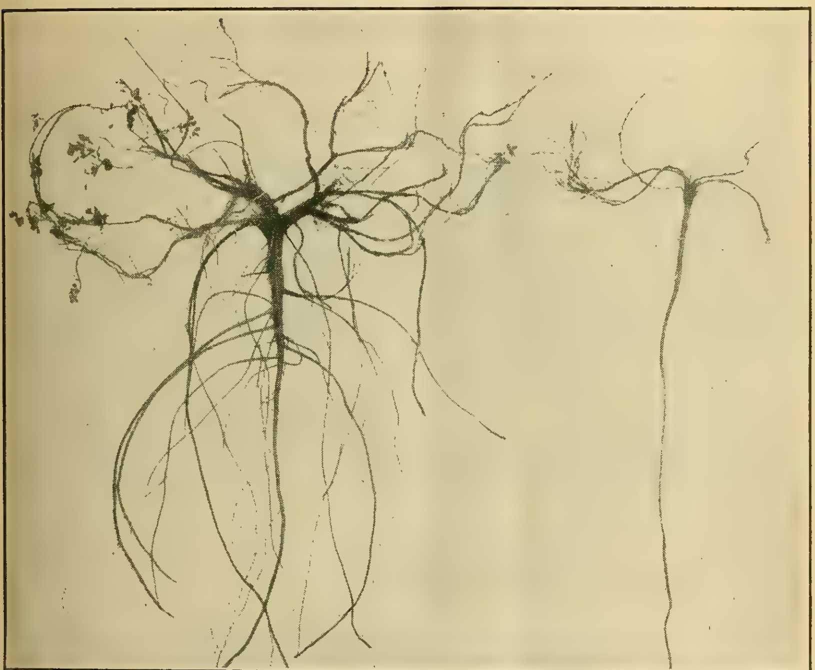

FIG. 17.—Root systems of prostrate yellow-flowered alfalfa plants having distinct taproots, the growth of six seasons.

Root proliferation has been observed in *Medicago falcata* introductions from Orenburg, Russia, and Semipalatinsk, Siberia. This characteristic has also been observed in some hybrid alfalfas. True lateral roots have been found extending parallel to the surface for 36 inches, at a depth of 4 to 12 inches. At irregular intervals the root enlarges to about double its normal diameter. These enlargements or swellings send out aerial shoots and may or may not develop fibrous roots. (Fig. 19.)

[9] S. P. I. No. 33465 (*Medicago falcata*), from Semipalatinsk, Siberia; presented by G. T. Miroshnikoff, at the request of Frank N. Meyer. Received Feb. 19, 1912.

SUMMARY.

Factors tending to produce modifications of taproots in alfalfa are soil, climate, cultural treatment, and injuries.

Studies made at Redfield, S. Dak., were on varieties seeded at the same time and grown under the same soil and moisture conditions. Even with the greatest care, however, it is difficult to make allowances for differences in root growth of the various varieties, owing to the nonuniform thinning of the stand by severe climatic conditions or other causes.

The varieties and strains studied include Peruvian, Poona, southern-grown common, northern-grown common, Turkestan, Grimm, and yellow flowered. The root systems of the Peruvian and Poona alfalfas of one season's growth are quite similar. They are charac-

FIG. 18.—Root systems of decumbent yellow-flowered alfalfa plants, the growth of six seasons.

terized by small, upright crowns, distinct taproots, comparatively few branch roots, and few fibrous roots, which are distributed rather uniformly over the root system. They differ in that the Poona seldom has branch roots on the upper portion of the taproot.

For convenience, the common alfalfas are divided into two classes. the southern-grown common and the northern-grown common. All these alfalfas have distinct taproots and in general show considerable similarity. The northern-grown strains have somewhat broader crowns and they exhibit more of a tendency to throw out branch roots and fibrous roots, but these differences are not sufficiently marked to constitute conspicuous characteristics. Both exceed the Poona and Peruvian alfalfas in branch and fibrous root development. There is practically no difference in the diameter of the taproot.

Turkestan alfalfa is characterized by broader, deeper set crowns, nore numerous branch roots, and shorter, more tapering taproots han the common and nonhardy alfalfas. The root system of this lfalfa is very similar to Grimm.

Grimm alfalfa is characterized by broad, deep-set crowns and umerous branch and fibrous roots. There is almost no difference n the diameter of the taproots of Turkestan and Grimm alfalfa, but oth somewhat exceed the common and nonhardy strains in this re-pect. They are also similar in the angle which the branch roots orm with the taproot. This angle is greater than in the less hardy arieties studied, but does not constitute a conspicuous characteristic.

IG. 19.—New plants that have developed from true lateral roots of yellow-flowered alfalfa.

ibrous roots are distributed over the root system, and rooting hizomes are well developed.

The forms of *Medicago falcata* are characterized by broad deep-set rowns and an abundant development of fibrous roots and branch oots. They exceed all the other alfalfas studied in these respects. rown branches and rhizomes are small and numerous. The angle f divergence is greater than in the variegated and common alfalfas. Based upon manner of growth, these alfalfas may be divided into hree general classes: The erect, the prostrate, and the decumbent. The erect plants have relatively small but quite distinct taproots nd numerous small, slowly tapering branch roots. The prostrate

plants have very broad, deep-set crowns, well-developed rhizomes, and dense root systems. Taproots are either absent or very indistinct. The decumbent form is intermediate between the other two forms. The taproots are indistinct, short, and rapidly tapering. This strain had the most extensive root systems of all the alfalfas studied.

A comparison of the different kinds of alfalfa reveals striking differences between certain varieties and strains. There are outstanding differences between the root systems of southern-grown common and yellow-flowered alfalfas in the prominence of the taproots, the development of branch roots, the number and development of rhizomes, and in the number and place of most profuse production of fibrous roots. Between many plants of common alfalfa, especially of the less upright forms, and many plants of the Turkestan and Grimm alfalfas, however, differences are not great, and it is often impossible to determine by their root systems the groups to which these plants belong. In brief, the root systems of the least hardy forms of purple-flowered alfalfa may be distinguished from the most hardy hybrid and yellow-flowered alfalfas with accuracy, but the intermediate forms are not sufficiently distinct to be distinguishable from one another or invariably from some forms of the nonhardy or yellow-flowered alfalfas.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1088

Washington, D. C. PROFESSIONAL PAPER July, 1922

ZYGOBOTHRIA NIDICOLA, AN IMPORTANT PARASITE OF THE BROWN-TAIL MOTH.

By C. F. W. Muesebeck,[1] *Scientific Assistant, Gipsy Moth and Brown-tail Moth Investigations, Bureau of Entomology.*

CONTENTS.

INTRODUCTION.

One of the most effective factors in the control of the brown-tail moth (*Euproctis chrysorrhoea L.*) in the United States is the introduced tachinid fly *Zygobothria nidicola* Townsend. Strangely enough this European parasite had not been described at the time it was first obtained in this country. The first adults were reared at the Gipsy Moth Laboratory, then located at North Saugus, Mass., in the summer of 1906, from brown-tail moth caterpillars that had been received from Europe during the preceding winter. The specimens were referred to Mr. C. H. T. Townsend, of the Bureau of Entomology, United States Department of Agriculture, for identification. After some correspondence with European authorities, to whom also specimens were submitted for examination, Mr. Townsend concluded that the species was new, and subsequently described it under the name *Zygobothria nidicola*.[2]

Much difficulty was experienced in rearing adults of the parasite for colonization from imported brown-tail moth larvæ. This was due to the great mortality among the caterpillars, particularly from

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[1] Special acknowledgments are due Mr. A. F. Burgess, in charge of Gipsy Moth and Brown-tail Moth Investigations, for helpful criticism of this bulletin, and Messrs. S. S. Crossman and R. T. Webber, of the Gipsy Moth Laboratory, Melrose Highlands, Mass., for many suggestions during the prosecution of the work.

[2] TOWNSEND, CHARLES H. T. THE TAXONOMY OF THE MUSCOIDEAN FLIES, INCLUDING DESCRIPTIONS OF NEW GENERA AND SPECIES. *In* Smithsonian Miscellaneous Collections, v. 51, p. 99–101. 1908.

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disease, before the parasites completed their development. Despite the discouraging results of the breeding work, however, *Z. nidicola* became established, and by 1910 had definitely taken its place in our fauna. The trying experiences of the laboratory force, in their attempts to establish this parasite, are interestingly recounted by Howard and Fiske.[3]

DISTRIBUTION IN THE UNITED STATES.

Because it evidently has no hosts other than the brown-tail moth the parasite must necessarily remain within the area over which this insect occurs; but within these limits it appears to be widely distributed, although it is relatively less abundant in the sections where very low temperatures are reached during the winter. It has been recovered from Rhode Island to northeastern Maine—very abundantly in the former region, sparingly in the latter. This wide dissemination, within some seven or eight years, is very largely the result of natural spread, since there has been little artificial colonization of this species.

LIFE CYCLE OF THE BROWN-TAIL MOTH.

Before taking up in detail the biology of the parasite it will be well to review briefly the life cycle of its host. During July the female brown-tail moth deposits her eggs on the underside of a leaf of one of the favored food plants—apple, pear, oak, or wild cherry. Usually the terminal leaves of the uppermost shoots of the tree are selected for oviposition. The eggs hatch in about three weeks and the small caterpillars feed on the epidermis of the leaves, preferring the terminal ones, which they gradually tie together with a large amount of silk. This process is slow, but ultimately a firm, tough web, about 3 or 4 inches long, is formed. By this time the majority of the slowly growing larvæ are in the third stage and are ready for hibernation. In the spring feeding begins as soon as the buds open, and continues until the middle of June, when cocoons are formed and pupation occurs. Moths issue during the first half of July, and, after a few days, lay their eggs. There is only one generation annually.

LIFE HISTORY AND BIOLOGY OF THE PARASITE.

EMERGENCE AND LONGEVITY OF THE ADULTS.

Adults of *Z. nidicola* appear during the latter half of July. They are very sturdy flies (Fig. 1) and endure unfavorable conditions well, normally living for a period of at least several weeks. Some

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[3] HOWARD, L. O., and FISKE, W. F. THE IMPORTATION INTO THE UNITED STATES OF THE PARASITES OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH. U. S. Dept. Agr., Bur. Ent. Bul. 91, p. 289–295. 1911.

specific data with regard to the length of life were obtained from laboratory experiments in which various types of cages were used. These consisted of: (1) Plain glass cylinders, measuring 50 by 200 mm., closed at one end; (2) ordinary shell vials, 22 by 100 mm.; and (3) a wooden cage, which had been successfully used by Mr. J. J. Culver in his life-history studies upon *Compsilura concinnata* Meigen, a tachinid parasite of both the brown-tail moth and the gipsy moth.

The glass cylinders were rather satisfactory for two to five flies each, when a bit of crunched crêpe paper was placed inside to afford the flies a good footing, but it was necessary to change the cylinders

FIG. 1.—Adult male of *Zygobothria nidicola.*

every few days because they quickly became dirty and sticky, and this involved a good deal of work. This objection applied to the shell vials as well, which in addition were found to be too small even for individual flies. The wooden cage was by far the most satisfactory. It measures about 12 inches square and 4 inches high, and is fitted with a cloth bottom to facilitate cleaning after each experiment; the top is a piece of window glass of the proper size. One-inch holes bored in the sides of the box and covered with fine wire gauze insure good ventilation. Another opening of the same size is fitted with a cork and is used for introducing the flies. Feeding is facilitated by the use of a larger opening, about 2 inches in diameter, which can be closed with a wooden stopper. After the flies were placed in this cage they were left entirely alone save for the feeding, which

was done on alternate days. This process merely involved slipping a narrow strip of blotting paper, which had been soaked in a mixture of honey and water, into the cage, and removing the old strip which had been placed there two days before.

Only a small proportion of the flies confined in the glass cylinders or shell vials lived from 25 to 28 days, and then only upon receiving particularly good care; those in the wooden cages which were given comparatively little attention lived five weeks and more. Two males and one female, which were confined in one of these wooden cages, were apparently in as good condition at the end of a 40-day period, when the experiment was discontinued, as when first placed in the box; several larger lots did about as well. The data obtained certainly demonstrate the ability of *Z. nidicola* to live a long time; and since even at best the artificial methods of the laboratory probably can not provide the equivalent of natural conditions, it seems safe to assume that in nature the average life of *Z. nidicola* is at least 25 to 30 days.

EMBRYONIC DEVELOPMENT.

Mating takes place within a few hours after emergence, sometimes even before either fly has fed. Following impregnation the uterus of the female fly gradually becomes much elongated and coiled, ultimately attaining a length of 7.5 to 8 mm., which is about the length of the entire insect. This enlargement results from the stretching of the walls of the organ as the enormous numbers of fertilized eggs pass into it and arrange themselves in more or less regular spiral layers. Embryonic development requires from seven to eight days. At the end of this period the lower part of the uterus contains a considerable number of maggots, each still enclosed within its egg-chorion. From 12 to 16 days after impregnation two-thirds of the 600 or more eggs in the uterus have fully formed first-stage maggots within them, if the fly has not been ovipositing as rapidly as they have developed.

OVIPOSITION.

The female fly prefers as its victims brown-tail moth caterpillars that are from several days to two weeks old, but even those just out of the egg are often successfully parasitized. Most of the oviposition by this species takes place during the first three weeks of August, in normal seasons.

Oviposition was readily obtained in the laboratory by confining a fertilized female fly in a shell vial with a few brown-tail moth larvæ that had been placed upon a small piece of cherry leaf. Having found the caterpillars, the parasite manifested much interest, passing slowly from one larva to another and inspecting each minutely. Then, with her face but a few millimeters from one of

the caterpillars, she slowly and deliberately pushed her abdomen downward and forward until the ovipositor plates were even with her face. With a quick movement the ovipositor was then pushed beneath the larva, and an egg with a first-stage maggot within it was deposited. The egg is almost invariably placed on the venter of the host, and usually occupies a transverse position between two pairs of true legs, or, less frequently, between two pairs of prolegs. Occasionally an egg is placed on the dorsum by accident, but in such cases the parasitic maggot is unable to enter its host—at least this was true of instances under observation in the laboratory. The explanation probably is to be found in the thicker skin of the dorsum, which is not so easily pierced by the small maggot.

Although only one parasite can complete its development in one host larva, the fly uses no discrimination when depositing her eggs; she places eggs as readily upon larvæ already having eggs upon them as upon those not yet attacked. From five to eight eggs have been found on one caterpillar. That this takes place under field conditions as well as in the laboratory has been disclosed by dissections; from 6 to 10 first-stage maggots of the parasite have been not uncommonly dissected from single field-collected brown-tail moth caterpillars.

EGG.

As deposited, the egg measures from 0.42 to 0.45 mm. in length by 0.11 to 0.12 mm. in width; the maggot within is 0.33 to 0.35 mm. long and 0.08 to 0.09 mm. broad. In form the egg is elongate-oval, somewhat narrowed at the posterior end, and concave on the lower side; in color it is whitish. The thin and delicate chorion is transparent. When viewed from above the egg appears opaque; this is due to what seems to be a special layer of protecting tissue just inside the chorion; it is limited to the posterior three-fourths of the egg, and occurs only above the maggot. It is peculiarly reticulated, being marked off into very slender hexagons, the outermost of which are incomplete. Its position suggests its function to be that of affording protection to the young maggot before the latter succeeds in boring into its host.

ENTRANCE OF MAGGOT INTO HOST.

Having been placed upon its host the parasitic maggot begins to cut through the thin egg chorion that confines it, and as soon as this is done it bores into the caterpillar. The posterior end of the parasite remains inside the eggshell until the opening into the host has been made; when this has been accomplished it requires but a fraction of a second for the maggot to pull its whole body into the caterpillar. In one case under observation the entire process of cutting through the egg chorion and the host skin and entering the

brown-tail moth caterpillar was completed within 10 minutes after the egg had been deposited. From many observations it appears that normally 20 to 30 minutes elapse between oviposition and the entrance of the parasitic larva into its host. Often the caterpillar makes vigorous attempts to destroy the maggot before the latter has made its way inside, and occasionally these efforts are successful, particularly if the egg of the parasite was deposited near the posterior end of the host. In this case the brown-tail moth larva, by doubling its body, can reach the parasite and crush it with its mandibles.

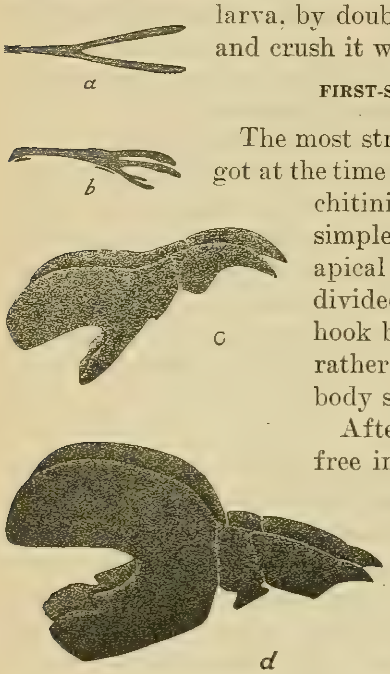

FIG. 2.—*Zygobothria nidicola*: *a*, Mouth hook of first-stage maggot, dorsal aspect; *b*, mouth hook of first-stage maggot, lateral aspect; *c*, mouth hook of second-stage maggot; *d*, mouth hook of third-stage maggot.

FIRST-STAGE MAGGOT OF THE PARASITE.

The most striking thing about the parasitic maggot at the time it enters the caterpillar is the strongly chitinized mouth hook (Fig. 2, *a*, *b*). It is simple in this stage, consisting of a single apical tooth and comparatively narrow, divided, posterior plates, the entire mouth hook being one solid structure. A pair of rather indistinct spiracles open on the last body segment.

After entering its host the parasite lives free in the body cavity for about 10 to 14 days and feeds on the fat body of the slowly developing caterpillar. Then it enters the œsophagus and remains here throughout its hibernation period of about nine months. It may lie longitudinally disposed or it may lie obliquely; apparently no particular part of the œsophagus is preferred, but usually the head of the parasite is directed toward the anterior end of its host. From dissections it appears that the maggot lies in a cyst against the inner wall of the intestine. Here, of course, it does not feed at all.

Rather severe competition is encountered from two hymenopterous parasites, *Apanteles lacteicolor* Viereck and *Meteorus versicolor* Wesmael, which also hibernate in the small brown-tail moth caterpillars. The presence of either of these parasites in the same host with Zygobothria produces the death of the latter. The exact nature of this peculiar influence exerted by the hymenopterous parasites upon the dipterous larva has not yet been demonstrated. Death

may perhaps result from a direct secretion of the hymenopterous species, or it may follow some special reaction on the part of the host; at no time has evidence of active combat been found.

In the spring the brown-tail moth larvæ that have hibernated begin feeding as soon as the buds open, but the Zygobothria maggots, in their cysts in the œsophagus, remain inactive for several weeks longer. It is not until late May and early June, when the host larvæ have molted into the last stage, that the parasite leaves its cyst in the fore-intestine and again enters the body cavity of the caterpillar to feed. Invariably it works its way at once to the posterior end of the host. After three or four days it is found to have established communication with the outside air through an opening in the integument of the brown-tail moth larva. From this minute, more or less circular opening there proceeds a rapid growth of the integument into the body cavity. This ingrowth takes the form of a funnel, within which the parasite lies, its posterior end directed toward the small opening, its anterior end free in the fat and fluids of its host. Thus the parasite has procured for itself an independent air supply. On the outside of the integumental funnel layers of soft tissue, evidently consisting of hypodermal cells, leucocytes, and compressed fat cells of the caterpillar, are gradually laid down, one upon another, until a thick, fleshy wall has been formed about the funnel.

The manner in which the opening through the body wall of the brown-tail moth larva is effected was not observed. Possibly it results from irritation by the spines at the caudal end of the parasitic maggot.

SECOND-STAGE MAGGOT OF THE PARASITE.

Very soon after becoming established in the posterior end of its host, and in the integumental funnel, the parasite molts into the second stage. The first-stage skin is pushed back upon the funnel where it is readily detected by the presence of the mouth hook. The second-stage maggot is distinguished from that of the first stage by its larger size, the much heavier mouth hook, and the presence of a pair of anterior spiracles, often difficult to locate, situated between the second and third body segments. Instead of the single apical tooth of the first stage the mouth hook now has two teeth, the pharyngeal skeleton having divided longitudinally over its anterior half; furthermore, there is now an indistinct transverse joint near the middle of this anterior portion. The posterior plates of the mouth hook are much stouter than in the first stage.

Throughout this instar, which requires from 8 to 12 days, the maggot remains in the integumental funnel. It grows rapidly during this period so that it measures about 4 mm. in length when ready to molt into the third and last larval stage. By this time the host has spun its cocoon.

THIRD-STAGE MAGGOT OF THE PARASITE.

When the second-stage skin is molted it is pushed back upon the funnel, as was that of the first stage; the mouth hooks of the two instars at this time are easily seen on the mass of yellowish tissue that surrounds the chitinous funnel itself. The particular points of difference between the second and third stage maggots are the larger size of the latter and its much heavier mouth hook. The mouth hook is divided longitudinally as in the second stage, but there are now two joints in the anterior part of the skeleton, one near the middle, corresponding to the single joint of the second stage, and another near the base of the very broad posterior plates. The anterior spiracles, opening between the second and third body segments, are much more distinct than in the second instar.

FIG. 3.—Brown-tail moth caterpillars containing puparia of *Zygobothria nidicola.*

This stage is the shortest of the three, requiring only four or five days. The host larva is killed just before the end of this period, with the destruction of its vital organs, and the parasite forms its puparium in the integumental funnel inside the host.

The puparium is about 8 mm. long and is dark brownish red in color; the posterior end is a little depressed, and the two anal stigmata (Fig. 4) within the depression are slightly elevated. Dead caterpillars that contain puparia of *Z. nidicola* (Fig. 3) are easily detected; they are greatly shortened, being scarcely longer than the puparia within, and are slightly inflated.

FIG. 4.—Anal stigmata of puparium of *Zygobothria nidicola.*

The period spent in the puparium averages from 25 to 30 days, after which the flies appear, some 8 to 16 days prior to the hatching

of the eggs of the brown-tail moth. This is just time enough to insure fertilization and development of the ova. Thus the life cycle of *Zygobothria nidicola* fits perfectly into that of its host.

ECONOMIC IMPORTANCE OF THE PARASITE.

Although *Zygobothria nidicola* has only one generation a year, and is handicapped by its absolute dependence upon the brown-tail moth, it has become a common species in New England. This means that it is of very great importance in the natural control of the brown-tail moth. Especially in the southern part of the infested area has the parasite proved remarkably effective, despite the fact that it is always the loser when in competition with *Apanteles lacteicolor* or *Meteorus versicolor*. In dissections of thousands of hibernating brown-tail moth caterpillars from all sections of New England it has been common to find from 20 to 30 per cent parasitism by Zygobothria.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1089

Washington, D. C. September 22, 1922

REINDEER IN ALASKA.

By SEYMOUR HADWEN, *Chief Veterinarian and Parasitologist*, and LAWRENCE J. PALMER, *In Charge of Grazing Investigations, Bureau of Biological Survey.*

CONTENTS.

INTRODUCTORY.

Reindeer grazing is an industry of the arctic and subarctic regions. In northern Norway, Sweden, Finland, Russia, and Siberia it dates far back in history and is of considerable economic importance.[1, 2]

[1] Laufer, Berthold, The reindeer and its domestication: Mem. Amer. Anthr. Ass'n., vol. 4, no. 2, pp. 91–147, April–June, 1917.

[2] Hatt, Gudmund, Notes on reindeer nomadism: Mem. Amer. Anthr. Ass'n., vol. 6, no. 2, pp. 75–133, April–June, 1919.

NOTE.—This bulletin presents the results of the first detailed studies of reindeer grazing, range and herd management, forage plants, and of diseases and parasites, with methods for their control. For distribution to those interested in improving the herds and developing the reindeer industry as one of the major resources of Alaska.

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Attempts were begun about 30 years ago to establish reindeer in the Territory of Alaska, the climate and vegetation of a large part of which are closely similar to those of regions occupied by reindeer in Old World countries. In 1891, 10 animals were brought in from eastern Siberia, and in 1892, 171 more, and these, with others intro- duced from the same source during subsequent years up to 1902 brought the total importations to 1,280.[3, 4] This most admirabl project was carried through by the U. S. Bureau of Education on th initiative of Sheldon Jackson in order to provide a means of liveli hood for the Eskimos in Alaska, whose former hunting resources wer rapidly decreasing. The original, or "mother," herd was establishe at Teller, on Seward Peninsula.

Conditions in Alaska proved so congenial to the reindeer that fron the comparatively insignificant breeding stock imported the increas has been extraordinarily rapid. At the present time, a little mor than 30 years after the first importation of 10 animals, without hav ing complete accurate counts, the number of living reindeer in Alask is variously estimated at from 130,000 to 250,000, with the actua number perhaps approximately 200,000. In addition, it is estimate that about 100,000 have been killed for food and clothing. Begu as an experiment, reindeer grazing in Alaska has amply proved it practicability and demonstrated its importance as one of the grea future industries of the Territory.

All of the original importations of reindeer were for the benef of the Eskimos. In order to teach the natives the proper methoc of caring for the herds, the Bureau of Education brought Laplande herders from northern Norway. A system of apprenticeship fc Eskimos was established, through which, as they became practiced i herding, they would become individual owners of reindeer, under restriction forbidding the sale of does. The Laplanders also wei granted a certain part of the increase as their exclusive property i order to maintain their services and interest.

For a long period no other white men owned any reindeer, bı gradually the Laplanders have sold parts of their holdings, until the present time one-fourth or more of all the reindeer in Alaska a under white ownership. One company at Nome is reputed to ow herds totaling more than 25,000 animals. Through this white owne ship definite efforts have been made during the last few years to pla the industry on a commercial basis. Several small refrigeratir plants have been established on the coast, and shipments of carcass

[3] Jackson, Sheldon, Introduction of domesticated reindeer into Alaska: 1st to 16 Ann. Repts. of General Agent of Education in Alaska to Commissioner of Educati U. S. Dept. Int., 1890–1906 (1891–1908).

[4] Grosvenor, Gilbert H., Reindeer in Alaska: Nat. Geogr. Mag., vol. 14, no. 4, pp. 12- 149, April, 1903.

have been made to Seattle and distributed to large cities in various parts of the United States, where the meat has met with favor and sold at good prices.

Previous to 1920 the reindeer industry in Alaska had been handled under the crude methods of the original herders and without the benefit of any definite scientific investigation or oversight. It had become increasingly plain to the white owners that troubles were developing among the herds which called for investigation and remedy such as is afforded other branches of the modern live-stock industry. As a result, in July, 1920, under authorization of an appropriation by Congress, the Biological Survey established a reindeer experiment station at Unalakleet, on the shore of Bering Sea, 60 miles north of the port of St. Michael, and provided ample equipment for laboratory and other investigational purposes. The staff of experts in charge of the work undertaken were Dr. Seymour Hadwen, chief veterinarian and parasitologist, with his assistant, Dr. George F. Root; and Lawrence J. Palmer, in charge of grazing investigations, assisted by Herbert W. Johnston.

The research staff was instructed to make a close study of the parasites and diseases of reindeer and of methods of combating them; and also to study grazing conditions, forage plants, and herd management over as wide an area as practicable. Another experienced field man, Donald H. Stevenson, as reservation warden of the Aleutian Islands Bird Reservation, was given headquarters at Unalaska and instructed to make a careful reconnaissance of the many islands in that group to determine their availability for reindeer grazing and fur farming. In addition, O. J. Murie, an experienced field naturalist, was stationed in the interior, with headquarters at Fairbanks, to study the caribou herds of that region, which for many years have been of the utmost importance as a source of meat supply to the prospectors and miners over a vast territory remote from ordinary supply points. The conservation of these native caribou herds is a matter calling for serious attention, and the information resulting from this investigation will be invaluable for use to that end.

An additional reason for the caribou work is to locate the most readily available source of supply of the largest caribou bulls to be used to interbreed with reindeer and thus grade up the size and vigor of the latter. The carcasses of reindeer shipped from Alaska have an average weight of about 150 pounds. Large woodland caribou are much heavier and many of the bulls are reported to weigh well above 300 pounds dressed. I am convinced that by the use of these bulls, and with proper methods of selection exercised among the breeding stock of the herds, the weight of reindeer carcasses can be practically doubled within a few years.

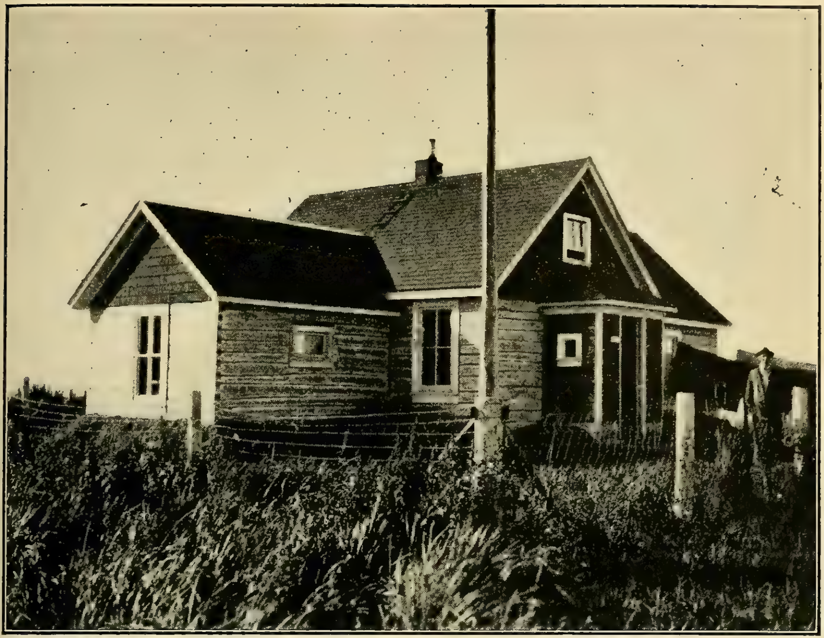
One of the most gratifying results of the work undertaken in 1920 has been the appreciation and interest shown by all those in the reindeer business, both natives and white men, and the open-minded way in which a number of herd owners are already putting in effect the improved methods suggested. It is perhaps even more gratifying to be able to say that communications are being received, stating the benefits that have already become evident from the change in management. This receptive attitude of the herd owners indicates that all that is necessary for the general and rapid improvement of the industry is to continue to provide the necessary skilled leadership.

The reconnaissances already made indicate that the Territory has available grazing sufficient to carry between 3,000,000 and 4,000,000 reindeer. The annual surplus from that number would yield a meat product each year worth more than the precious metals mined in the Territory and second only to the fisheries as a permanent income-producing asset.

I wish to take this opportunity of expressing my appreciation of the competent and energetic manner in which instructions given in this work have been carried out by the staff. Doctor Hadwen and Mr. Palmer, after 15 months of field work, submit herewith a preliminary report on the results of their investigations, which it is believed will be of substantial and practical value in the development of the reindeer industry.

I desire also to acknowledge with appreciation the valuable assistance rendered the Biological Survey in the conduct of this work. In Alaska the Bureau of Education and its field representatives have been very helpful, allowing the use of one of their buildings at Unalakleet as the laboratory and living quarters of our staff (Pl. I, Fig. 1); the Lomen Co. and other white owners have cooperated whenever occasion arose; and the Eskimos were everywhere hospitable and eagerly helpful. For assistance in laboratory studies of material the Bureau of Entomology and the Bureau of Animal Industry have rendered every assistance. Help in identifying plants has been given by G. K. Merrill, of Rockland, Me.; R. S. Williams, of the New York Botanical Garden; Paul C. Standley, of the United States National Museum; and Miss Flora Patterson, of the Bureau of Plant Industry.

E. W. Nelson,
Chief of Bureau.



B20467

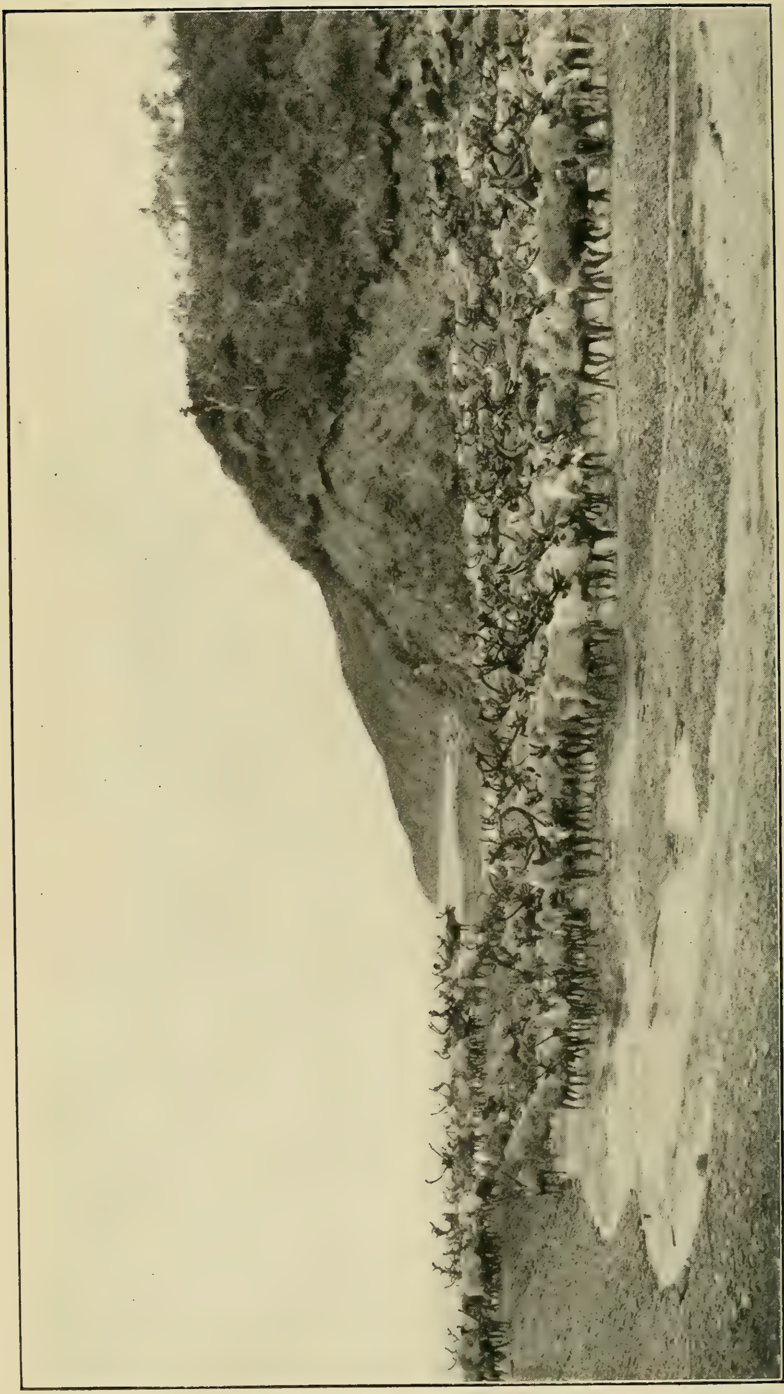
FIG. 1.—REINDEER EXPERIMENT STATION AT UNALAKLEET, 1921.

The wing at the left served for laboratory purposes, and the remainder of the house was used by the staff for living quarters.

B20469

FIG. 2.—MOUTH OF UNALAKLEET RIVER, NEAR REINDEER STATION.

Hauling winter supplies from boat to store by dog team, October 20, 1920. The schooner *Hazel*, on the right, was purchased by the Biological Survey in 1921 for the use of the staff in its field work.



B22686

UNALAKLEET NATIVE REINDEER HERD ROUNDED UP ON BEACH AT MARKING TIME, JUNE 27, 1921.

BIOLOGY OF REINDEER.

DESCRIPTION.

The typical reindeer of Alaska (*Rangifer tarandus*) (Pl. II) is colored approximately as follows: The neck and shoulders are a grayish white, becoming darker on the back, and shading into the much darker sides of the abdomen and hind quarters; the legs are dark to almost black; around the root of the tail there is a whitish area that descends between the legs; the head is dark, except for the muzzle; and the mane, which becomes long in winter, is almost white. In viewing a herd from a little distance, the various colors unite to give the appearance of soft browns and grays with a tinge of yellow. In conformation the reindeer is symmetrical, and gives the impression of blockiness, as in a well-bred beef animal. The average full-grown reindeer stands about 13 to 13½ hands high, and measures about 7 feet from nose to tip of tail.

As compared with the caribou (*Rangifer stonei* and related forms), the general color aspect is similar; but the caribou on the whole is lighter colored, having a white belly and less black on the legs. The caribou is much longer of leg and more ungainly in appearance. Its nose is inclined to the Roman type, and the underlip is short and drawn up, whereas the reindeer is frequently dishfaced, and the underlip is not nearly so trim. The ears of the caribou are a trifle larger.

Reindeer and caribou have the distinction of being the only members of the deer family in which both sexes have horns. These secondary sexual characters are nearly as large in the female as in the male, and it would seem possible that her powers of prepotency may be greater than in the females of other deer. In the course of the investigations in Alaska, a doe was rarely seen which did not have a fawn colored and shaped like herself. As regards color and conformation, the female seems to impress her characters strongly on her offspring (Pl. III, Figs. 1 and 2). Under present conditions where the sire is unknown it is difficult to generalize, but to a geneticist reindeer should be of special interest, since there has been so little interference by man in its breeding, with the exception of the preservation of the white animals.

White and spotted reindeer (Pl. IV, Fig. 1) are common in Alaskan herds. The spotted animals do not seem physically deficient, but the white animals are inferior to those of normal color. They are generally smaller in stature and seldom look robust. Their horns (Pl.

period of shedding for the female herd as a whole covers a comparatively long period, since the fawning season extends from April 10 to the end of the first week in May. On April 20 some hornless does may be seen, but these are few in number. The shedding increases day by day until the peak is reached early in May, the last horns falling off about the 20th of the month. Occasionally does may give birth to fawns before or after the ordinary season, and in this event she casts her horns after the fawn is born. In one case a doe that dropped her fawn about August 28 was noted with one horn shed and the other clear of velvet on September 19.

Bucks.—Reindeer bucks $2\frac{3}{4}$ years of age and over drop their horns after the rutting season in November. The coming 2-year-old bucks shed their horns shortly prior to the time the females drop theirs. About the middle of November, in one of the herds at Unalakleet, there were observed many hornless bucks. Early in January, in two large herds which were counted, no bucks over $2\frac{3}{4}$ years old were in possession of horns. In contrast to this, none of the coming 2-year-old bucks had shed their horns at that time. Apart from lack of horns, it is easy to pick out the bucks which have been rutting, as they are gaunt and tucked up in the flanks, whereas those under 2 years of age are usually in good condition. As the bucks cast their horns much earlier than the fawns or does, the new horns are far advanced in growth before those of the other members of the herd, and by the middle of April they may attain a length of 18 inches.

Steers.—Castration has a remarkable effect on the horns, these secondary sexual characters being materially affected by any form of injury to the reproductive organs. It has been a common practice in Alaska to castrate the bucks that have been in service one or two years. Many are castrated in August, just before the beginning of the rutting season, i. e., after the velvet has peeled or "set" on the horns, and within the next two to three weeks the horns fall off (Pl. VI, Fig. 1). When the horns are in the velvet and are growing at the time of castration the effects are quite different, in that both the horns and velvet remain on. Properly castrated steers retain the velvet until the horns fall off in the spring. If the operation has been only partially successful, as is often the case with the Lapp method, the effect is again different. The shock of the operation may cause the horns to fall off, but the following season, when the new horns appear, these partially sterilized animals show some signs of rutting, the velvet is partly peeled off the horns, and other evidences of sexual activity are shown. When an animal has been properly castrated (the glands entirely removed) it is docile and the velvet remains intact on the horns (Pl. VI. Fig. 2).

B22745

FIG. 1.—SPOTTED REINDEER DOE AND FAWN.

The resemblance between the two is marked. Females have horns, like the males. They appear to be very prepotent and impress their characters strongly on their offspring.

B22707

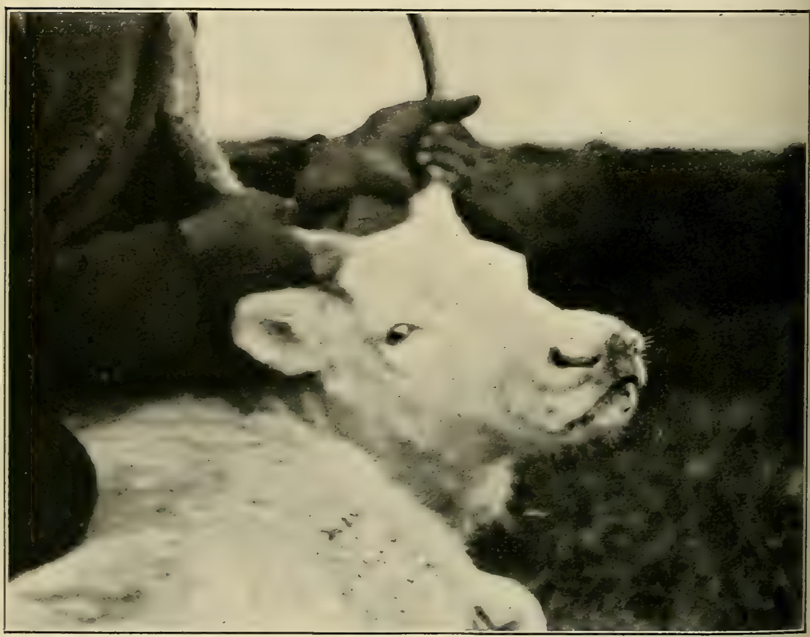
FIG. 2.—LIGHT BLUE-ROAN DOE AND PROGENY.

Resemblance in color and form is noticeable.

B20527

FIG. 1.—REINDEER IN THE VELVET.

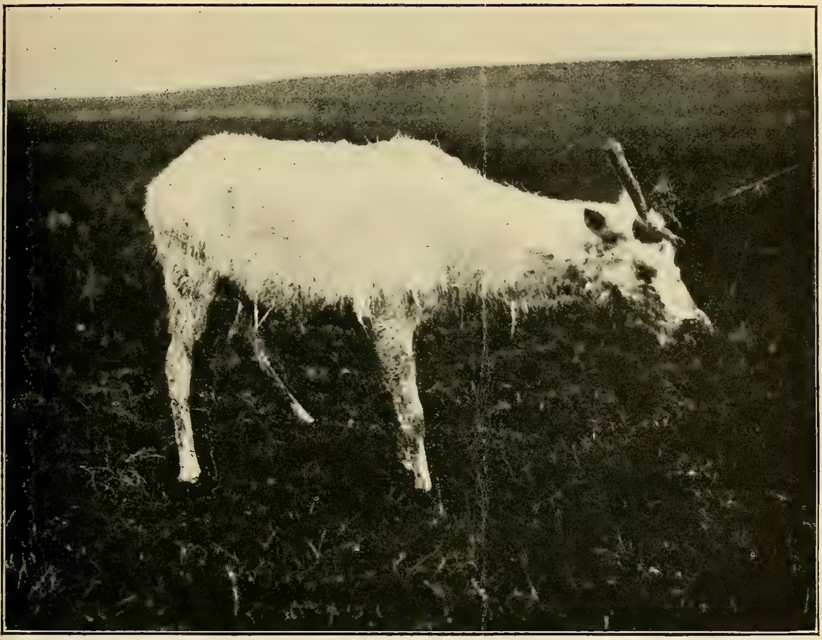
The spotted doe on the right is a well-shaped animal. While not so desirable as animals uniformly colored, spotted reindeer are nearly normal in all but color, thus differing from the pure white ones, which are obviously defective. On the left is an old female which has outlived her usefulness. The unshed winter coat is a mark of diminished vitality and indicates that the animal should have been killed for meat the previous fall. (Photograph by Lomen.)



B22719

FIG. 2.—WHITE REINDEER.

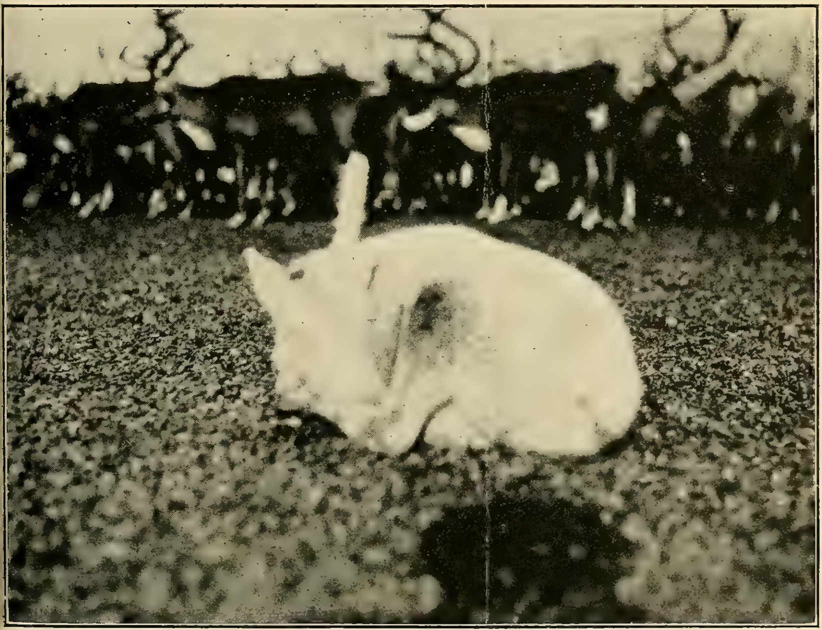
The characteristic dark pupil indicates that white reindeer are not true albinos. Lapp herders value a white animal here and there as an aid in locating the herd at a distance.



B22690

FIG. 1.—WHITE DOE, WITH CHARACTERISTIC POORLY DEVELOPED AND ROUND-ENDED HORNS.

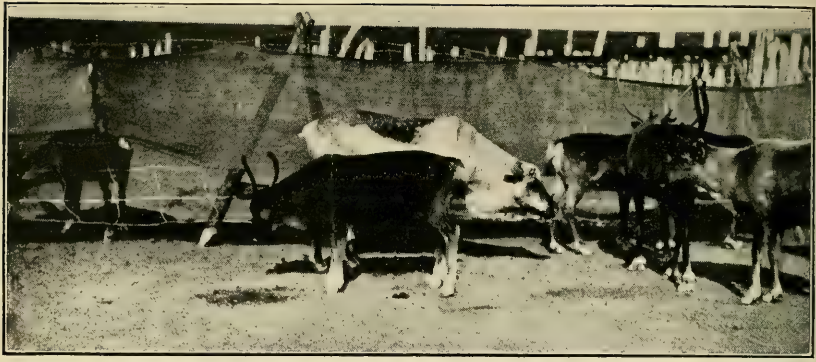
Animals of this type should be eliminated, as they produce undersized fawns and thus lower the quality of the herds.



B1925M

FIG. 2.—WHITE FAWN.

White reindeer are deficient in many respects. Their eyes are weak, and they lie and sleep much of the time. As a result they are easily approached and become the prey of wild animals.



B22739

FIG. 1.—HORNLESS, PARTLY WHITE, REINDEER.

This animal, in center, had been castrated about three weeks before. When the operation is performed after the velvet has been lost, the horns drop a few weeks later. The burlap covering the corral wall prevents the animals from seeing outside and thus makes their control easier.

B22629

FIG. 2.—SLED DEER, VELVET INTACT.

Photographed in January. This animal, properly castrated, had not rubbed the velvet from the horns as do normal bucks.

B22693

FIG. 3.—REINDEER SHEDDING THEIR COATS.

Photographed on July 25, 1921, on St. Lawrence Island. The bucks shed first, in spring, then the steers and young stock, the does a little later, and, last of all, the sick and old animals. On the left is an old doe shedding her winter coat.

GROWTH OF HORNS.

The growth of the horns is so rapid that at times the animals show signs of some irritation or perhaps even of pain. It has been observed that they are constantly touching them with the hind fetlocks, but they do this very gently and with a sort of rubbing motion. Evidently the horns at this stage are so tender that care is taken not to injure them. Once the growth is complete and the velvet has become avascular, the animal's attitude changes and the horns become weapons of offense and defense.

SHEDDING THE VELVET.

As the bucks shed their horns the earlier, it is natural to expect that they would peel off the velvet before the other sex. The earliest signs of peeling noted were on July 31, but it was not until August 15 that the horns were becoming clean and polished; and even then, in a good many cases, there were still strips of velvet hanging to them. The horns are entirely clean and the rutting season has begun by approximately August 25. Most of the does shed the velvet by August 20, although strips of it may still be adhering to the horns of many up to September 10 and even later. The fawns shed a little later than the does. Properly castrated steers should have the velvet intact at this time (Pl. VI, Fig. 2).

SHEDDING HAIR.

The bucks are the first to shed the hair in spring, and by the middle of June most of them will be in good coat. Females, in some districts at any rate, are a week or two later. Yearlings correspond more to the does in time of shedding. It has been noticed that old or diseased animals are slower in shedding than those that are healthy, and ragged-coated does have been seen up to the first days of August. As the hair is closely related to the horns histologically, it will be seen that the shedding of hair links up closely with the growth of the horns (Pl. VI, Fig. 3).

ALASKAN AND NORWEGIAN REINDEER COMPARED.

An importation of Norwegian reindeer into the United States in March, 1922, afforded opportunity of making a comparison between them and the Alaskan species. The reindeer in the Norwegian shipment compare very unfavorably with the ordinary run of reindeer in Alaska, and, in comparison with the best Alaskan animals, so far as concerns size and general appearance, they can be rated as very inferior. Full-grown Alaskan reindeer measure 13 hands and over. The largest Norwegian buck and doe measured only about an inch over 10 hands. The largest Norwegian buck weighed 175 pounds and the largest doe 148 pounds.

The Norwegian animals had just landed after a long, rough voyage, but even when fed they would fall short of the average weight of Alaskan reindeer, which for steers average 150 pounds dressed. The ages of the Norwegian animals ran between 3 and 4 years.

The Norway reindeer differs a little from the Alaskan animal in being lighter colored. At first sight more white was noticeable around the feet and legs, and in some instances the belly was almost white. As a rule, the sides of the belly in Alaskan reindeer are very dark and in some cases almost black. In other respects the marks are almost identical.

REINDEER AS RANGE STOCK.

OWNERSHIP OF REINDEER.

The ownership of the reindeer herds in Alaska now falls largely into three classes: Eskimos, white men married to Eskimo women, and other white men, including Lapps. Formerly herds were also owned by the Government and by the various missions located in Alaska, but these owners have practically dropped out, as also have many of the Lapps. While no complete information as to exact numbers of reindeer or exact ownership is available, it is generally considered that, on the basis of an estimated total of 130,000 animals, the whites, including Lapps, now own about 40,000 to 45,000, and the Eskimos the remainder, or some 85,000 to 90,000. In 1917, the Bureau of Education reported the Eskimo ownership to be distributed among 1,568 natives.

The ownership of reindeer among the natives is not uniform. There are numerous small owners, each with a few head, often only 2 or 3, and a few Eskimos are large owners, with several hundred to a thousand animals. Among the whites, aside from the Lapps, and those married to native women, who for these purposes are classed as natives, ownership is as yet limited, being largely confined to the relatively few who have been able to buy the herds that had been acquired by the Lapps and the missions.

Up to within a few years, the Alaska reindeer industry had been largely a native enterprise and development has been entirely under the supervision of the Bureau of Education. The Eskimos were taught herding and given ownership in reindeer through a system of progressive apprenticeship under instruction of the Lapps brought over from northern Norway for the purpose. The reindeer were originally imported for the Eskimo, and the policy of the Government was to limit ownership as much as possible to the natives, but an exception was made in the case of the Lapp herders and of missions. Largely through recent purchases of herds from

these latter owners, white men have been able to become owners and to enter the industry.

In the beginning it was no doubt necessary to exclude the white man from ownership in order to insure protection for the native, but since the latter is now well started in the reindeer industry and since there is sufficient room in the grazing areas for both the natives and white men, there appears to be no longer any reason why the white man should be excluded. As a matter of fact, white ownership of herds is now needed to assure the desirable economic development of the industry. This is particularly so, since at this stage there is great need for more capital and initiative to establish the means of transportation and marketing necessary to put the industry on a commercial basis.

INCREASE OF HERDS.

There are in Alaska about 100 herds of reindeer, widely distributed from the north shore of the Alaska Peninsula to Point Barrow and from the shore of Bering Sea eastward into the interior above Ruby on the Yukon and to the vicinity of Flat on the upper Kuskokwim River. Plans are in progress to establish a herd in Broad Pass, on the Alaska Railroad, during 1922.

The growth of the reindeer industry in Alaska in the period of 20 years from 1902 to 1921 shows an annual net increase of about 27 per cent, or, taking into consideration the estimated number of stock slaughtered during that period, an annual gross increase of about 33⅓ per cent. This rapid increase from the small beginning in 1902 indicates a promising future. Swedish figures for reindeer place the herd profit, or net increase, in normal years at 25 per cent.[5] The average fawn crop in Alaska runs between 50 and 60 per cent, although the average prolificacy of reindeer is indicated as about 70 per cent, with the highest percentage as 85 to 90.

As a general rule, in the fawns the relative numbers of the two sexes are remarkably close, practically 50 per cent of each. These figures are of interest as indicating the possibilities in reindeer grazing. Under present management there is a wide margin of loss, but under improved methods this can be materially reduced. While the recorded losses in the herds are incomplete, in adult reindeer the annual average is about 6.5 per cent and in fawns about 15 per cent. Losses in adults are largely attributed to diseases and parasites, injury in handling, predatory animals (including dogs), and straying; losses in fawns are attributed to desertion by mothers, stillbirths, predatory animals, and parasitism.

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[5] Guinchard, J., Historical and statistical handbook: Swedish Government, Industries, 2d ed., Stockholm, 1914.

There is usually only one fawn at a birth, and twins rarely occur. The newborn fawn is remarkably hardy, and is strong and fleet of foot soon after birth. Alaskan records are not sufficiently complete to show to what age the average doe reindeer continues to breed, but it is generally estimated at about 12 years. Yearling reindeer sometimes reproduce, but in the Alaskan herds this is not common.

UTILIZATION OF REINDEER.

Reindeer are of value principally in the production of meat for food and skins for clothing.[6, 7] In Alaska they have been used thus far only to a limited extent as beasts of burden, for packing in summer, and for drawing sleds in winter. They will later have an added value, in the utilization of such by-products as the horns, head, and offal, and other parts of the carcass now wasted in slaughtering.

The skin is used chiefly for winter clothing, and in the north for sleeping bags. The meat is fine-grained, contains a good, palatable fat, and is not "gamy" in flavor when properly produced and handled, but compares favorably with beef. The liver is not unlike calves' liver and, as it is of large size, makes an important item of food. The tongue and heart are both of good flavor and quality.

Present regulations governing the native industry prohibit the slaughter of does. The average life of a reindeer is about 15 years. Full maturity is reached in 4 or 5 years, but nearly full growth is attained in the third year. Of the bucks a certain number are set aside for breeding purposes and the rest are raised as steers, to be butchered when about 3 years old.

The dressed weight of full-grown Alaskan reindeer will range anywhere up to 200 pounds in the best-handled herds. The average dressed weight, however, for 3-year-old steers is about 150 pounds. By cross-breeding with caribou and following a process of selection and grading-up of the stock in the herds, the weight eventually will be much increased. The Alaskan caribou of certain districts will often weigh more than 300 pounds dressed, without the skin. The weight of the fresh reindeer skin is generally estimated to be 10 per cent of the total weight of the dressed carcass.

SLAUGHTERING AND HANDLING MEAT.

Modern slaughtering methods are not used in Alaska, except in a very few herds. Reindeer are killed at all seasons of the year, both in and out of condition. At present each native goes out by himself

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[6] Lomen, Carl J., The camel of the frozen desert: Nat. Geogr. Mag., vol. 36, no. 6, pp. 538–556, December, 1919.

[7] Lomen, G. J., The reindeer industry in Alaska: Journ. of Heredity, vol. 11, no. 6, July–August, 1920.

at irregular periods to kill his animals, by shooting on the open range. Under this method the herds are constantly being disturbed, and through the mistakes which often occur friction is caused among the owners. Furthermore, when the carcasses are dressed on the open range the work is usually badly done. As the native animals are under supervision, it should be an easy matter to have all killing done cooperatively, and in autumn, when the deer are fattest. Satisfactory cold-storage rooms could be made in the underground ice at many of the villages. If all killing were done when the animals are at their prime, and the carcasses were packed into these rooms after being solidly frozen with the hair on, they not only would keep satisfactorily for long periods, but the objectionable features of irregular killing would be eliminated.

Methods of killing.—Reindeer may be either shot or pithed, either method being satisfactory. In cattle, pithing has been the subject of much controversy, many people believing that as the brain is uninjured when the animal falls, it still has consciousness and feels pain. In reindeer these objections do not obtain, as in one single thrust with the knife held obliquely the spinal cord at the base of the brain and the brain itself may be penetrated. Consequently, when the animal falls it makes no further movement and registers no feeling of pain.

The method of killing employed by the Lapps in Alaska is to drive a knife through the brisket and into the heart, and bleeding takes place into the chest cavity. This is done to save the blood, which is used for human food or given to dogs. It is not considered good practice, however, since the bleeding is not so free and complete as when the throat is cut; furthermore, the animal is not stunned before the knife is driven in, and consequently the method is inhumane. There is no question that cutting the throat to bleed the animal after it has been properly stunned or pithed is by far the better method.

Skinning and dressing carcasses.—In preparing reindeer carcasses the skins are removed as are those of cattle. The skinning is even easier than in the case of cattle, since the hide can be loosened almost entirely with the fist, very little knife work being necessary. When only a few animals are being dressed at one time on the open range, it is convenient to have a tripod with block and tackle suspended underneath for hoisting the carcasses. The herd may be driven close up and a sled used to drag the carcasses to the tripod.

The greatest care should be exercised to keep the carcasses clean (Pl. VIII, Fig. 1). The worst trouble in connection with the Alaskan meat trade undoubtedly arises from spoilage on account of the various molds growing on the meat, and these can be kept out to a large

extent by thorough cleanliness. In cold weather it is out of the question to wash carcasses, and therefore the greatest care must be used to keep them free from dirt. The man who does the butchering should handle nothing but the carcass. Where proper slaughterhouses are available and animals are butchered before severe cold weather, portions of the carcass may be washed if running water and a brush are used. Cloths and a bucket of water should never be used, on account of the danger of spreading molds from one carcass to another. Special care must be taken to avoid contaminating the interior of the carcass with contents of the stomach, which are apt to regurgitate up the gullet, since it is probable that the food contains the spores of molds. The gullet should be tied as a precautionary measure.

A most important point in the prevention of molds is to keep the frozen carcasses at a uniform temperature, to give the molds no chance to grow. With fluctuating temperatures in the cold-storage room, molds gain rapid headway and the meat soon spoils. Furthermore, alternate thawing and freezing injures the cells and thereby lowers the quality of the meat.

Hides should be left on the carcasses intended for shipment out of Alaska. Skinned carcasses are much more likely to mold and also to lose their color and to shrink more in weight. When the hide is left on, the brisket is frequently left closed and the pelvis need not be split. If the brisket is not split the carcasses pack together much better. One point which must be kept in mind in this connection, however, is that the animal heat does not leave the body as quickly when the carcass is not skinned or completely opened. Reindeer hair is an excellent nonconductor and prevents the heat from leaving the body very rapidly. Hence, cold storage should be available to cool the animals as soon as possible after slaughter in summer. Cold-storage rooms should be disinfected at intervals. Information received from the meat inspection division of the Bureau of Animal Industry indicates that strong hot brine applied to the walls of a storage room is very efficacious in keeping down molds.

Bucks should never be killed for food, as the meat has an objectionable odor and taste and spoils easily. Some bucks have been killed for marketing, but the practice is an indication of carelessness and bad management, especially where the killing is done late in the year, or after the rutting season has begun. If bucks are to be slaughtered they should be castrated just prior to this period, or about the middle of August. The animals will then fatten and be in condition to kill later in the season and will not have the strong odor and taste.

Fawns are frequently killed in great numbers at marking time, in some cases owing to injuries received in the corral, and at other times to provide skins for making parkas, sleeping bags, and other articles. The meat of the fawn is of good quality and is used locally. It has been recommended that old does be slaughtered after they have passed the breeding age. If fat, these animals produce excellent meat, and while they are naturally a little lighter than the steers, they can be used to supply the local demand.

Time for slaughtering.—It is frequently stated in Alaska that reindeer are fit to kill in the latter part of July and early in August. Even though the animals look fat at that time, however (Pl. VII, Fig. 1), the meat is soft and watery and the back fat, being in a growing condition, is vascular and red. There is no comparison between this meat and that which is killed later in fall, at which time the fat is white and firm.

The best time for slaughtering is in October and November. Steers are at their prime in October, although the meat is in almost equally good condition during September and November. In September, however, rutting is in progress and the herds should not be disturbed. When December is reached the condition of the animals begins to deteriorate, and at that season the parasitic warble grubs have developed to a considerable size, so that from December onward the meat becomes of less and less value.

All domestic animals store up a reserve supply of fat before the advent of winter. As a rule this is laid on evenly, and generally a large part of it will be found on the omentum, or leaf, in the abdominal cavity. In the case of reindeer, the leaf fat is in small quantity and the winter reserve is laid on the back in two masses; hence it is called back fat. This is relished by the natives perhaps more than any other part of the reindeer, and by the whites it is often cut into strips and used like bacon. It does not have the strong flavor of mutton tallow and is a valued food in the North.

In the accompanying illustration (Pl. VII, Fig. 2) it will be seen that the fat lies on either side of the backbone. It starts just level with the root of the tail, with the greatest thickness 2 to 3 inches over the rump, and tapers off like a wedge in front of the kidneys. In reindeer the thickness of this layer is a true indication of the fatness of the animal, for, as it is laid on last, it means that all other parts of the animal are fully stocked with fat. Consequently, the time for slaughtering is when the back fat is at its thickest.

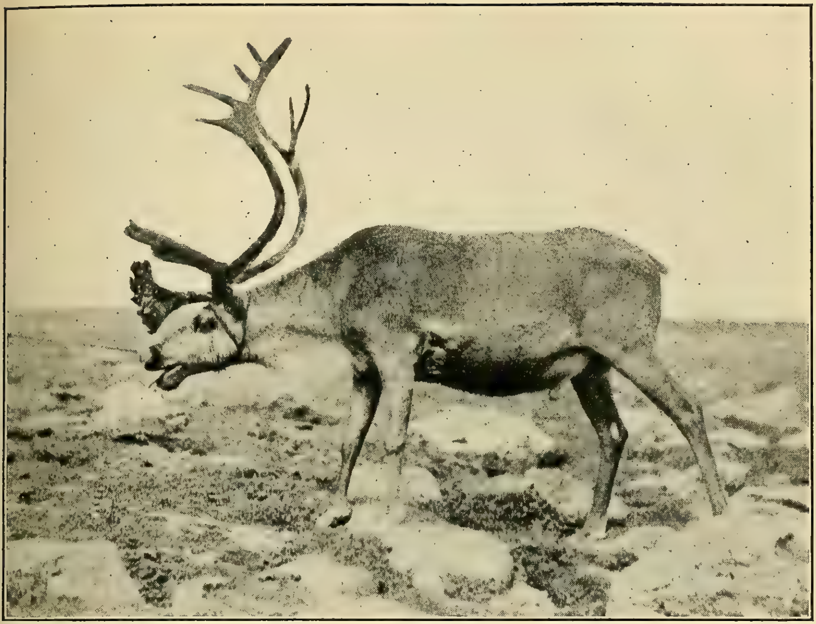
Cutting up a carcass.—The Lapps employ what is considered a very good method of cutting up a carcass. The head is severed at the first joint (atlas). The neck piece includes the first two ribs.

The brisket is removed by cutting through the ribs along the cartilages, and the abdominal muscles go with it. The cut follows the flanks up to the stifle joint. The backbone is removed entire, the heads of the ribs being disjointed at their points of attachment. The front leg is cut off at the elbow joint and the hind leg at the stifle. This leaves two sides with the shoulders and hams attached. Later the sides are cut into three pieces, leaving the hindquarters, ribs, and shoulders. The reason for cutting the legs so high is to save the sinews. The back sinew, which is the most valuable in the body, is removed from the long muscles of the back and the back fat is taken off. The saving of the sinews is important, since they are valuable for sewing purposes, the market value of a set from one animal being, in 1921, about $1.50. This method of cutting up a carcass is good when at a reindeer camp or out in the hills. It can be done on the ground in a cleanly manner and a knife is the only instrument required.

Utilizing natural cold storage.—A deep layer of permanently frozen earth and underground ice along the coast of Alaska offers natural cold-storage facilities so readily available in a large part of the Territory that it is surprising so little use has been made of it. In a few instances small storage rooms have been made by hewing out chambers in this frozen layer, but so far as can be ascertained the only large storage room in use is one made by the Bureau of Education at Point Barrow. In many places on the Seward Peninsula and elsewhere the frozen layer is composed of crystalline ice free from impurities. Its depth has not been ascertained by the authors, but shafts have been sunk in it to a depth of 20 or 30 feet. Covering the ice usually is a layer of soil one or more feet in thickness. In some places there are frozen beds on hill slopes, so that the storage rooms constructed in them could be entered on a level through a tunnel and thus obviate any danger of flooding from surface water or melting.

In such a bed of ice the problem of keeping meat should be a simple matter. In another paragraph it has been recommended that reindeer be slaughtered after the cold weather has set in. Frozen carcasses could then be packed into one storage room at a time, which could then be carefully sealed. Double doors and sawdust will be necessary to insulate each room thoroughly. In this way it can be confidently predicted that meat can be kept almost indefinitely and at a trifling cost.

Marketing and transportation.—The market in Alaska for reindeer meat is as yet largely local and therefore limited by reason of the small and scattered population and the generally poor transportation facilities. Of the total native and white population of



B22671

FIG. 1.—STEER IN SUMMER CONDITION (JULY).

At this time of the year the animals are fat, but the meat is watery and the fat reddish. The abdomen is large because of the watery vegetation in the summer food.

B20752

FIG. 2.—REINDEER HINDQUARTER IN NOVEMBER.

The layer of back fat lying between the muscles of the back and the skin in this animal was 2 inches thick. This layer is like tallow and is put on in fall as a reserve food supply and absorbed during the winter.

B20514

FIG. I.—DRESSING REINDEER FOR MARKET.

Carcasses being prepared at Nome by a white butcher, assisted by Eskimos. (Photograph by Lomen.)

B20526

FIG. 2.—REINDEER DRESSED FOR SHIPMENT.

On lighter alongside slip at Nome, ready to go on board. Reindeer meat is shipped every year to the United States, mainly in fall. (Photograph by Lomen.)

the Territory (54,899) only about 25,000 live within the area to which reindeer grazing applies, and only about 15,000 within the immediate reindeer districts now holding herds. The Eskimo and Indian population alone is about 25,000.

The reindeer of the Eskimos furnish meat and skins for the most part to the owners, but a portion of the surplus is sold in local mining camps or in white settlements. The Lapps and other whites likewise have a similar sale for a limited portion of their surplus, but for the most part the Lapp has depended upon a market for his reindeer in the sale of breeding stock to other whites.

In marketing locally the reindeer are usually driven to the town or camp where sale is to be made and there slaughtered. Usually long drives are necessary, and they are generally undertaken in the early part or middle of the winter. The white man is largely a beginner in the industry and is looking toward its larger development and to an outside market, the opening up of which has just begun (Pl. VIII, Fig. 2).

Transportation in northern Alaska during the winter is almost entirely by dog team (Pl. I, Fig. 2) and in summer by boat. Horses are used to some extent in the interior. The new railroad between Seward and Fairbanks should prove a vastly important factor in establishing the reindeer industry in the interior. Aside from the railroad, transportation between the United States and northern Alaska is by boat and limited to the summer and fall months. During the winter most of Bering Sea is covered with pack ice, so that navigation is impossible.

Development of regular markets and better means of transportation and marketing are particularly necessary at this time to place the reindeer industry on a proper basis, and the establishment of a definite cash market for his surplus stock will greatly encourage the Eskimo as well as the white man to adopt improved methods of management.

BY-PRODUCTS.

Up to the present time by-products from reindeer have been to a large extent neglected. Some hides, which are used in the manufacture of leather goods, have been exported, and in a few instances the horns have been shipped to be used for making knife handles and similar articles. The hair is of value for stuffing life preservers and filling horse collars, but has been little used for these purposes. In the slaughterhouses the blood and viscera have been thrown away, whereas they might be used for making meal for dog food. There

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is much room for development in the use of these by-product Under modern packing-house methods, more use will undoubtedly b made of many of the parts now being discarded.

TANNING.

The native methods of tanning hides in Alaska are primitive ar there is great need for improvement. Since reindeer skins are r quired for the making of clothing and other uses in the Territor it seems highly desirable that the Government provide an expert instruct the Eskimos in tanning.

The skins which come from Siberia have a much superior tan, ge erally speaking, than the Alaskan article; consequently large nur bers of hides are imported annually from Siberia by the traders f sale among both natives and whites. In fact, this trade is so larg that it is a considerable item in the list of Alaskan imports. In a dition to the tanned skins, made-up reindeer-skin parkas and oth articles of clothing are brought over each season. This trac could be saved to a great extent for the natives of Alaska if the knew better methods of tanning. With the rapid increase of th reindeer herds it is time to prepare an outlet for all reindeer b products.

REINDEER MILK.

Milk from reindeer is often used in making cheese, butter, et in other countries where the animals are raised. While the mil may be valuable as a food in Alaska, the natives and whites ha made no extensive use of it as yet, and at the present time mill ing is not done in any of the herds. The reasons for this are n far to seek. In the first place there are no inclosures or oth means available for holding the reindeer for the purpose of mill ing. Secondly, milking strains have not been developed.

When the Lapps first came to Alaska they practiced milkin to a limited extent. They state that when the herds were sma it was a comparatively simple matter. The procedure followed w to drive the herd to some convenient place each morning, whe the animals to be milked were caught one by one with the lass Each one yielded about a cupful of milk. It can readily be seen th this practice was neither economical nor good for the herd, an it was soon abandoned.

If the best milkers were picked and the fawns separated fro them, and in addition if the animals were kept in good fence pastures and properly taken care of, the yield of milk from rei deer could be greatly increased.

GRAZING AND RANGE MANAGEMENT.[8]

AVAILABLE GRAZING AREA.

Lands in Alaska available for reindeer grazing fall into two divisions—the coastal areas, immediately bordering the Arctic Ocean and Bering Sea, including the islands; and the interior areas, lying between those along the coast and the Canadian boundary. Along the coast summer grazing is mainly near the sea, where the reindeer can obtain salt, and on wind-swept areas where they are protected from insects. In the interior, summer grazing is on the windy mountain tops.

Most of the present grazing is on the coast ranges, which are most convenient of access and have better transportation facilities; the interior ranges, not so accessible, still remain largely untouched.

On the coast ranges, reindeer now graze from Point Barrow on the north to Bristol Bay on the south and also on St. Lawrence and Nunivak Islands, the Pribilofs, and Umnak and Atka in the Aleutian Chain. The main grazing, however, is about four chief centers, namely, the Kotzebue Sound country, Seward Peninsula, about Norton Sound, and in the Kuskokwim River basin.

On the far interior range (Pl. IX, Fig. 1), reindeer grazing to a small extent has been established at only three points, namely, on the upper Kobuk River, above Ruby on the Yukon, and on the upper Kuskokwim. While there had not been sufficient range reconnaissance to determine exactly the full range extent and its possible carrying capacity, it is apparent that there is still room for considerable expansion on the coast ranges, especially with the introduction of improved methods of handling the herds; and the far interior ranges present practically a new field which should prove important for the future expansion of the industry.

Expansion into the interior will depend primarily upon the availability and accessibility of suitable range sites. The popular belief that reindeer may be handled wherever caribou are or

[8] Since basically the principles of cattle and sheep grazing are largely applicable to reindeer grazing as well, the following publications dealing with phases of range and stock management are listed for reference:

Jardine, James T., and Mark Anderson, Range management on the national forests: Bull. 790, U. S. Dept. Agr., 1919.

Jardine, James T., and L. C. Hurtt, Increased cattle production on southwestern ranges: Bull. 588, U. S. Dept. Agr., 1917.

Jardine, James T., Improvement and management of native pastures in the West: Separate 678, Yearbook 1915, U. S. Dept. Agr., pp. 299, 310; 1916.

Jardine, James T., The pasturage system for handling range sheep: Forest Service Cir. 178, U. S. Dept. Agr., 1910.

Sampson, Arthur W., Range improvement by deferred and rotation grazing: Bull. 34, U. S. Dept. Agr., 1913.

Sampson, Arthur W., Natural revegetation of range lands based upon growth requirements and life history of the vegetation: Journ. Agr. Research, U. S. Dept. Agr., vol. 3, pp. 93–148, 1914.

Sampson, Arthur W., Plant succession in relation to range management: Bull. 791, U. S. Dept. Agr., 1919.

Jardine, James T., and C. L. Forsling, Range and cattle management in time of drought: Bull. 1031, U. S. Dept. Agr., 1922.

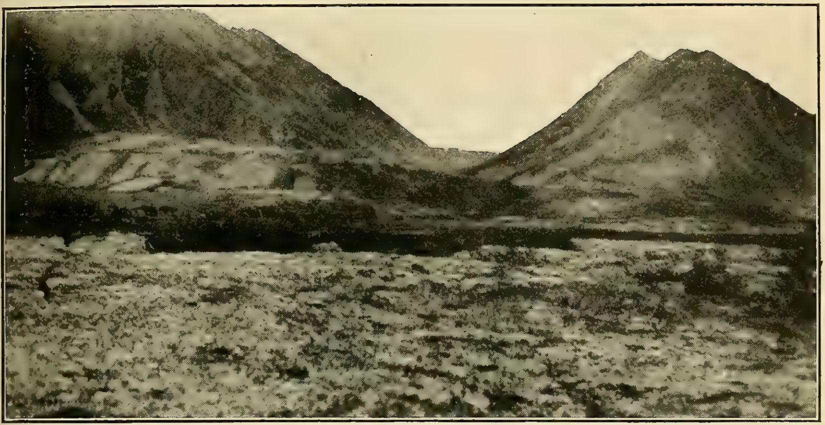
have been is only partially true. Caribou are not herded, but roa at will. By traveling in small bands and covering much territo they thrive on small moss areas and a certain amount of timb vegetation. A reindeer herder would have a hard time attemp ing to utilize some of these ranges. He might do so in some cas perhaps by adopting the nomadic mode of existence of the Lap of northern Norway and Sweden. In the large timbered areas the interior it is unlikely that a reindeer herd could be handle without considerable fencing. Grazing could be carried on succes fully, however, wherever there is suitable forage and an area lar enough to accommodate a reindeer herd the year round.

An accurate statement of the possible future carrying capacity Alaska for reindeer grazing can not be given until a complete ran reconnaissance has been made. Judging from a very general pr liminary survey of the field as a whole, there are probably betwee 150,000 and 200,000 square miles of open grazing lands availabl This area is estimated to be capable of supporting between 3,000,0 and 4,000,000 reindeer. The estimate includes all potential range on the islands, along the coast, and in the interior. Development some of these ranges for grazing, particularly in the interior, wi probably come only with a greater development of transportatic facilities, particularly roads. The immediate coastal areas and tho along navigable rivers and the Alaska railroad will undoubtedly l developed in the near future (Fig. 1).

RANGE SUITABLE FOR REINDEER.

The suitability of range for reindeer depends principally upo climate and forage and to some extent upon character of site. Th natural habitat of the reindeer is in the arctic and subarctic region and the animals will undoubtedly do best on ranges falling withi these climatic zones. Whether they can be grazed successfull farther south is not definitely known, but is a matter for experiment tion. Michigan is now (1922) undertaking the experiment and th results will be awaited with interest.

Reindeer on the range most closely resemble cattle, but band to gether more like sheep, and like the horse they trample over muc range in nervous feeding, but, unlike the horse, they travel again the wind. In winter they paw through the snow with the fore fe to reach lichens and other forage (Pl. X, figs. 1 and 2). Durin the summer they move about over the range a great deal, and at tim cover considerable distances against the wind. In winter they gra more quietly over a comparatively small area, and remain mainly i one general locality. At fawning time the herd divides, the do grouping by themselves and the bucks, steers, and some of the yea lings banding together elsewhere.



B23999

FIG. 1.—INTERIOR RANGE SUITABLE FOR REINDEER.

Vegetation mainly reindeer moss and browse, between 2,500 and 3,000 feet elevation. An unusually heavy growth of reindeer moss, both in the foreground and on the mountain slopes.

B22601

FIG. 2.—WET TUNDRA TYPE OF FORAGE.

Largely sedges and small browse growth, "niggerheads," characteristic of much of the summer range on the coast of Bering Sea. Reindeer fawn in the foreground.

B22589

FIG. 1.—REINDEER ON WINTER RANGE.

Photographed February 21, 1921, at Pikmikalik, between St. Michael and the mouth of the Yukon. The snowfall was light in this region in 1921 and the reindeer are seen grazing practically unhampered by it.

B22821

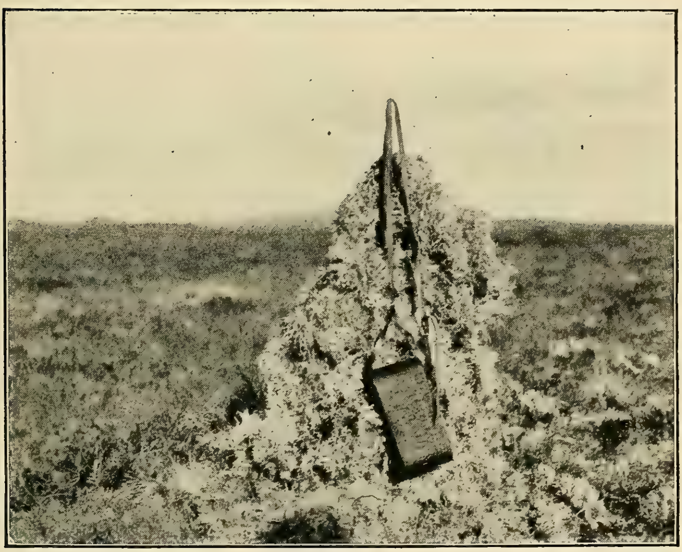
FIG. 2.—MOSS UNCOVERED BY REINDEER.

The herds paw through the snow with their forefeet to reach the lichens and other vegetation upon which they feed on the winter range.

B22815

FIG. 1.—LICHEN, OR "MOSS," TYPE OF FORAGE.

Characteristic growth on upper slopes of inland winter range back from the coast.



B22810

FIG. 2.—NEAR VIEW OF REINDEER MOSS.

Pile gathered from growth on a good winter range in three or four minutes within a radius of 6 or 8 feet.

B22794

FIG. 1.—SUMMER RANGE ALONG THE COAST.

Forage type mainly sedges, browse, mosses, and grasses.

B20747

FIG. 2.—WINTER RANGE BACK FROM THE COAST.

Vegetation mainly lichens, mosses, browse, and sedges.

Reindeer are attached to their accustomed haunts, and when well located on a range will unerringly return to it if moved away. With change in seasons, unless restrained, they instinctively seek their favorite winter, fall, or summer pastures. In the choice of summer pasturages, such reindeer pests as mosquitoes and warble flies play

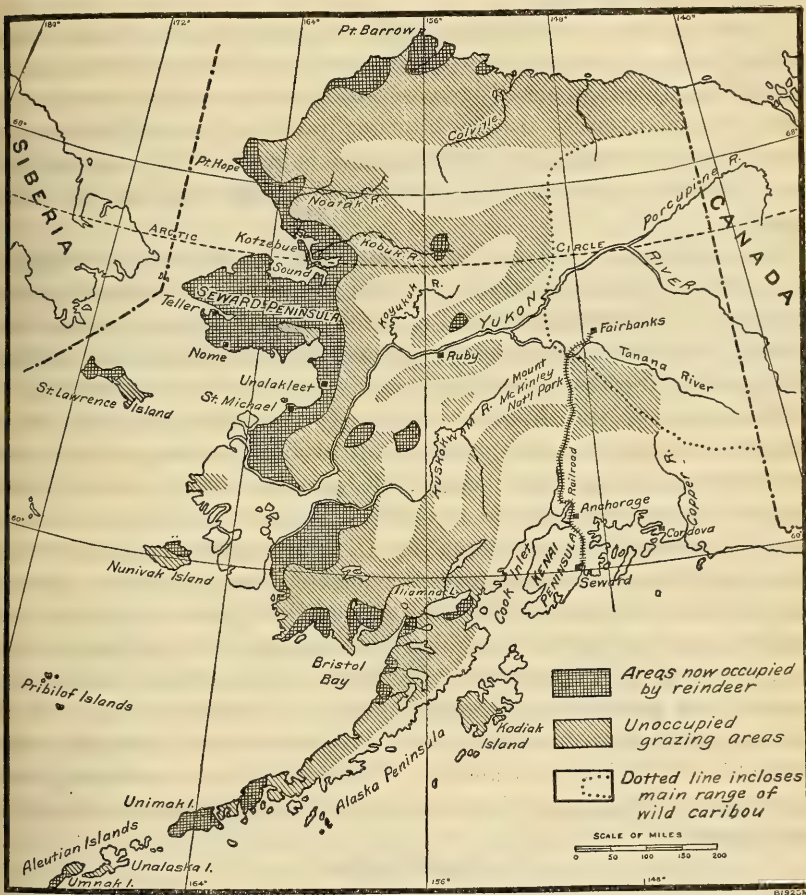


FIG. 1.—Preliminary map of reindeer grazing areas in Alaska, showing areas now partly occupied by herds of reindeer and areas not yet occupied but suitable for reindeer grazing. It should be understood that the grazing areas indicated are approximate only and will be largely modified by more detailed investigations. On the Pribilofs there are two small Government-owned herds, and a small herd is on Atka Island, in the Aleutian Chain, not on the map. The area inclosed by the dotted line shows range reserved for wild caribou.

an important part, causing the reindeer to seek the wind-swept areas adjoining the beach along the coast, and the wind-swept ridges and low mountain tops in the interior.

In the arctic habitat a range must be selected having available for winter grazing an area not subject to periodic crustings of the

snow. Where held too near the coast during the winter season, eve within the Arctic Circle, reindeer herds occasionally suffer conside able losses through starvation when winter rains fall on the snow In such cases the herd must be moved back to protected areas in th interior hills, but heavy losses may occur before the animals ca reach favorable ground.

Under ordinary conditions, depth of snow on the winter rang along the coast does not constitute a serious factor, since at least part of the area is generally exposed to the winds and so does not be come deeply covered. In the interior, however, particularly on tim bered flats and bench land country, there is less drifting, and depth o snow is then a matter to be considered in the selection of winte range.

The area selected for grazing should lend itself to the handling o the herd throughout the year. It should comprise a natural grazin unit, with the spring, summer, and fall, and the winter ranges com bined. In a timbered country, reindeer are difficult to herd success fully, and in the absence of fencing this is a factor to be considered.

The value of the different kinds of range forage plants varie greatly with the stage of growth, and probably to some extent with the tastes of the animals. As a rule, reindeer prefer green vegeta tion and fresh growths and are fond of variety. They feed upon a great number of range plants, but in winter graze especially upon mosses and in summer upon green vegetation (sedges, browse, grasses and weeds). In spring they seek the earliest green vegetation, and feed on green growth throughout the summer. In fall and winter they feed on dry vegetation of various kinds and on lichens and mosses, but prefer the lichens known as "reindeer moss," which having made new growth in fall, are fresher and probably more palatable (Pl. XI, Figs. 1 and 2). While the lichens represent princi-pally winter forage, they are also taken to a certain extent during the summer.

FORAGE COVER.

The character of vegetation along the coast is very similar through-out, the relative proportions of the various species and their density varying, however, with exposure and other conditions. The cover comprises a composite type of lichens, mosses, sedges, browse, weeds, and grasses, most of the summer range (Pl. XII, Fig. 1) containing a predominance of sedge and species of browse, and that of the win-ter a predominance of lichens and browse (Pl. XII, Fig. 2).

As a general rule, the percentage of lichens increases in the vegeta-tive type with the distance from the coast except in valley and basin areas. Very little timber occurs within the coastal areas—none at all over the major portion of Seward Peninsula, practically none

over the belt of summer range immediately adjoining the coast, and only very scattering stands over the neighboring inland areas which are chiefly winter range.

Immediately along the coast occurs the bulk of the forage most suitable for summer grazing, consisting largely of herbaceous and nonmoss growth; and adjoining this belt toward the interior lie the fall and winter ranges, covered largely with lichens. The belt of summer range will run from 7 to 30 miles wide, generally averaging about 10 to 15 miles, and the strip of winter range will equal and exceed this.

The vegetation along the coast is very luxuriant, especially on flats, benches, and lower slopes (Pl. IX, Fig. 2). A hummocky ground of moist to wet soil, called "tundra" or "niggerheads," predominates on the lower elevations, and a dry, generally rocky ground occurs on the upper slopes and the tops of ridges. The vegetation of the tundra areas is very dense, often matted, and is of profuse growth (Pl. XIII, Fig. 1). On the upper slopes and tops of ridges it is less dense and becomes dwarfed. On small areas of sandy soil which occur along the beach or in forested areas along streams, the grasses and weeds frequently attain a height of 3 and 4 feet. In many places the tundra growth of mixed sedges, browse, grasses, weeds, and lichens will form a vegetative mat 10 to 12 inches deep. Thickets of tall willow are often found along stream courses; scattering stands of alder and birch frequently occur on upper slopes or mixed with spruce along the larger river valleys; and a mixture of low brush, as ground birch, ground willow, huckleberry, salmonberry, cranberry, crowberry, and tea, is abundantly scattered throughout the ranges. Grasses and weeds are of only scattering occurrence. Sedges, browse, and lichens form the bulk of the vegetation.

While a general type of vegetative cover occurs over the coast ranges, the physical characteristics of the land and soil vary considerably, thus producing three main classes or types of range, which may be termed generally the dry tundra, the wet tundra, and the rocky areas. In terms of relative carrying capacity the dry tundra type should support a greater number of reindeer per acre than the wet tundra type. While both types will run about equally high in average forage production, the soft or marshy nature of the ground reduces the actual carrying capacity of the wet type because of the greater harm done to the forage plants in being ground into the wet earth by the trampling of grazing animals. On the other hand, the rocky type usually will have a lower carrying capacity than the other two, because of the smaller forage growth.

In the interior areas covered by preliminary reconnaissances, particularly the Tanana-Nenana River country, it was found that ranges best adapted to reindeer grazing lie generally between timberline (approximately 2,700 feet) and the snowline (approximately 6,000 feet). The growth cover on this range includes principally three main types of vegetation, namely, conifers, browse-lichens, and lichens, occurring largely according to zone. Browse and species of lichen predominate and, as compared with the coast range, there is a noticeable absence of grasslike vegetation, especially the sedge or "niggerhead" type (Pl. IX, Fig. 2). Up to between 4,000 and 5,000 feet a dense cover of vegetation occurs, lichens especially appearing in profusion. Between 4,000 and 5,000 feet up to 6,000 feet the rocky nature of the soil supports a cover of lower density. Above 6,000 feet the ground is perpetually covered with snow.

Around the lakes and along streams up to 2,500 to 3,000 feet elevation the principal types of vegetation are conifers with a browse-grass to browse-lichen subtype (Pl. IX, Fig. 1). This type blends into the browse-lichen and browse-grass types which extend up to 3,800 and 4,000 feet. Above 4,000 feet a nearly pure lichen type comes in, continuing up to snowline, at 6,000 feet. Up to 3,000 feet the conifers grow in scattering open patches, while above this elevation they become very small and scattering, and usually 2 to 3 inches in diameter. The browse, of which ground birch is the most abundant species, often occurs in very dense patches, chiefly in comparatively dry, gravelly soil. Willow grows on the more swampy areas and along stream courses. Alder is found in patches above timberline. Of the lichens, species of *Cladonia* are most abundant. On the river bars and the lower benches of the main drainages, grasses and weeds form the principal growths. On lower south exposures, grasses are often the main vegetation.

Forage types.—A summary of the principal forage types occurring on the immediate coast ranges, particularly of the areas lying between Nunivak Island and Kotzebue Sound, is given in Table 1. The general occurrence of the types is indicated and their relative forage value, the forage value as here used being derived by multiplying the percentage of density of forage stand by the percentage of palatable plants.

B22737

FIG. I.—NORMAL SUMMER RANGE.

On the coast of Norton Sound. Forage of the sedge, or tundra, type.

B22734

FIG. 2.—OVERGRAZED RANGE.

The result of close herding. On the coast of Norton Sound.

TABLE 1.—*Summary of principal forage types occurring on the coast reindeer range between Nunivak Island and Kotzebue Sound.*

Type.	Subtype.	Average forage value.[1]	Distribution.
Lichen		5.00	Ridges and interior hills; fall and winter range.
Do	Sedge	5.25	Do.
Do	Browse	5.50	Do.
Do	Grass	4.25	Do.
Sedge		6.00	Tundra types—on flats, benches, and lower slopes; summer and fall range.
Do	Browse	5.70	Do.
Do	Lichen	6.35	Do.
Do	Grass	4.95	Do.
Conifer		3.20	Along rivers and creeks.
Do	Grass	3.20	Do.
Do	Browse	3.90	Do.
Do	Lichen	2.50	Do.
Browse		4.45	Slopes and ridges; summer range.
Do	Grass	3.50	Do.
Do	Sedge	5.40	Do.
Grass		4.00	Over relatively small areas on sandy spits; coast types of summer range.
Do	Browse	5.00	Do.
Do	Weed	3.00	Do.

[1] Derived by multiplying the percentage of density of forage stand by the percentage of palatable plants.

TABLE 2.—*Summary of principal forage types occurring on some of the far interior reindeer ranges, particularly over the Broad Pass, Gulkana, and Tangle Lakes region.*

Type.	Subtype.	Average forage value.[1]	Distribution.
Lichen		5.75	
Do	Browse	6.50	Ridges, upper slopes and benches, and glacial canyons.
Do	Browse, weed	4.80	Upper steep slopes.
Do	Grass	6.00	Foothills of upper drainages.
Browse		6.40	
Do	Lichen	6.50	Lower ridges and slopes, and shallow draws of benchlands.
Do	Grass	6.15	Old burns, and in open parks in timber.
Do	Weed	6.65	Lower slopes.
Grass	Lichen	6.85	Benchlands.
Conifer	Browse	5.40	Along draws and around lakes.

[1] Derived as in Table 1.

FORAGE GRAZED BY REINDEER.

A complete list of the range forage plants observed and collected on the reindeer ranges in Alaska will be found on pages 70 to 74. The forage plants observed to be grazed by the reindeer during both summer and winter on the coast ranges are summarized in Tables 3 and 4, in which the species are grouped according to the proportions they form of the forage eaten, those in the "first series" being most generally used; the "second series" being next in importance; and the "third series" those which are grazed only incidentally.

The forage in the first series is of generally high palatability and the most extensively grazed, not only because of this but because of

its greater abundance. On the other hand, plants in the second series are of equally good quality, but are not eaten so much, chiefly because they are less abundant. The plants in the third series are generally of lower palatability. The division into groups indicates the relative degree of palatability within each series.

TABLE 3.—*Plants grazed in summer, in the order of their importance.*

- First series:
  - Group I—
    - Small cotton sedge (*Eriophorum callitrix*).
    - Large cotton sedge (*Eriophorum angustifolium*).
    - Willows (*Salix*) (several species).
    - Reindeer moss (lichens) (*Cladonia*).
    - Iceland moss (lichens) (*Cetraria*).
  - Group II—
    - Ground birch (*Betula rotundifolia*).
    - Alaska tea (*Ledum palustre* and *groenlandicum*).
- Second series:
  - Group I—
    - Blueberry (*Vaccinium uliginosum*).
    - Mountain cranberry (*Vaccinium vitis-idaea*).
    - Crowberry (*Empetrum nigrum*).
    - Sedges (*Carex*).
    - Grasses (*Poa; Arctagrostis; Festuca; Agropyron*).
    - Water buttercup (*Ranunculus pallasii*).
    - Valerian (*Valeriana capitata*).
    - Fernweed (*Pedicularis verticillata*).
    - Wormwood (*Artemisia tilesii*).
    - Wormwood (*Artemisia arctica*).
    - Fireweed (*Epilobium angustifolium*).
  - Group II—
    - Mushrooms.
    - Gentian (*Gentiana glauca*).
- Second series—Continued.
  - Group II—Continued.
    - Dryad (*Dryas octopetala*).
    - Lupine (*Lupinus*).
    - Vetch (*Vicia*).
    - Polygonum (*Polygonum alaskanum*).
    - Dock (*Rumex occidentalis*).
- Third series:
  - Group I—
    - Alder (*Alnus alnobetula*).
    - Salmonberry (*Rubus chamaemorus*).
    - Alpine bearberry (*Arctous alpina*).
    - Diapensia (*Diapensia lapponica*).
    - Clubmoss (*Lycopodium annotinum*).
    - Heath moss (*Polytrichum*) (several species).
    - Bunch moss (*Aulacommium turgidum.*)
    - Fern moss (*Hylocomium alaskanum*).
    - Horsetail (*Equisetum arvense*).
  - Group II—
    - Water starwort (*Merckia physodes*).
    - Beach pea (*Lathyrus maritimus*).
    - Timber bluebells (*Mertensia paniculata*).
    - Fernweed (*Pedicularis*).
    - Gentian (*Gentiana*).
    - Birch (*Betula kenaica*).
    - Spiraea (*Spiraea steveni*).
    - Parsnip (*Coelopleurum gmelini*).
    - Hemlock parsley (*Conioselinum gmelini*).

TABLE 4.—*Plants grazed in winter, in the order of their importance.*

First series:
- Reindeer moss (lichens) (*Cladonia*) (numerous species).
- Iceland moss (lichens) (*Cetraria*) (numerous species).

Second series:
- Group I—
  - Cotton sedges (*Eriophorum*).
  - Sedges (*Carex*).
  - Grasses (*Arctagrostis; Poa*).
  - Ear lichen (*Nephroma arcticum*).
- Group II—
  - Heath moss (*Polytrichum*) (several species).
  - Bunch moss (*Aulacommium turgidum*).
  - Clubmoss (*Lycopodium annotinum*).

Second series—Continued.
- Group II—Continued.
  - Fern moss (*Hylocomium alaskanum*).
  - Sphagnum moss (*Sphagnum fimbriatum*).
  - Pad moss (*Dicranum*) (several species).

Third series:
- Willows (*Salix*).
- Blueberry (*Vaccinium uliginosum*).
- Ground birch (*Betula rotundifolia*).
- Crowberry (*Empetrum nigrum*).
- Alaska tea (*Ledum palustre*).
- Mountain cranberry (*Vaccinium vitis-idaea*).

GRAZING PERIODS AND CLIMATE.

Reindeer raising is entirely a range proposition, involving yearlong grazing, with, generally speaking, a winter season varying from seven months on the coast range to six or six and a half months in the far interior. On the coast the grazing periods run about as follows: Spring, or fawning period, April 10 to June 10; summer, June 10 to September 15; fall, September 15 to November 15; winter, November 15 to April 10.

The seasonal periods applicable generally to reindeer grazing in Alaska are indicated roughly in Table 5, which includes figures on temperature and precipitation as recorded from climatological data collected by the United States Weather Bureau. Data are given for only a few widely scattered stations, but are thought sufficiently representative to afford a general idea of the climatic conditions covering the main reindeer area.

TABLE 5.—*Climatological data, by seasonal periods at various Alaska stations for the year 1919.*

Stations and districts.	Temperature (°F.).			Precipitation (inches).		
	Years recorded.	Annual mean.	Lowest.	Years recorded.	Total annual.	Snowfall.
Dutch Harbor, Aleutian Islands	18	39.5	5	18	64.98	5.0
Naknek, Bristol Bay	3	34.3	−43			
Holy Cross, Yukon River	17	28.3	−58			
Nulato, Yukon River	2	23.4	−57	3	17.18	68.4
Tanana, Yukon River	19	23.6	−66	19	13.33	21.5
Fairbanks, Tanana River	14	26.4	−56	14	11.44	29.6
Unalakleet, Norton Sound		23.6	−49			
Nome, Seward Peninsula	12	25.3	−47	12	19.04	54.9
Candle, Seward Peninsula	9	20.3	−60			
Akiak, Kuskokwim			−57			
Salmon River (Kuskokwim)						

TABLE 5.—*Climatological data, by seasonal periods at various Alaska station for the year 1913*—Continued.

Stations and districts.	Seasonal periods. (Spring: April–May; summer: June–September; fall: October–November; winter: December–March.)							
	Mean temperature.				Total precipitation.			
	Spring.	Summer.	Fall.	Winter.	Spring.	Summer.	Fall.	Winte
Dutch Harbor, Aleutian Islands	36.5	49.9	40.2	30.3	9.47	11.73	11.65	32.1
Naknek, Bristol Bay	36.9	53.0	29.2	16.6	3.61	11.29	4.40	3.0
Holy Cross, Yukon River	36.7	50.2	22.4	4.9	.72	13.17	4.83	.1
Nulato, Yukon River	31.7	49.3	15.1	−2.5	.70	9.25	4.57	2.6
Tanana, Yukon River	36.3	51.2	10.6	−4.0	.84	9.05	2.10	1.3
Fairbanks, Tanana River	41.3	55.2	13.6	−3.3	1.49	6.92	2.14	.8
Unalakleet, Norton Sound	28.8	46.9	17.0	1.2	......	......	......	......
Nome, Seward Peninsula	26.2	44.5	22.6	7.2	.52	10.94	4.61	2.9
Candle, Seward Peninsula	19.9	45.7	19.5	−4.4	.16	5.86	.73	......
Akiak, Kuskokwim	35.5	......	18.4	......	.46	......	.77	......
Salmon River (Kuskokwim)	36.9	52.8	16.6	......	......	......	......	......

RANGE MANAGEMENT.

No cultivated forage crops are raised and no feeding is done in connection with reindeer grazing. The individual grazing allotment, by which is meant a special kind of stock ranch, represent the requirement for maintaining a herd and includes summer and winter ranges and fawning grounds. Consequently the utmost car must be exercised and the best management maintained to insure a permanency of pasturage with a continued forage crop from yea to year.

All improvements, such as buildings and corrals for each herd should be constructed on the individual grazing allotment. Th ideal arrangement would be, with definite allotments established, entirely to fence each unit, particularly the summer range, and turn the reindeer loose within the inclosure to graze at will. Such a plan at this time, however, is not financially practicable. With improved methods of handling and control, grazing on the open range may in effect be made to approach this ideal, which implies more natural and open grazing. Under present handling, the tendency is to close herd and graze the reindeer more on the order of the old method of handling range sheep. The tendency should be toward open herding and grazing, more like the handling of range cattle in the Western States.

Unlike much of the reindeer grazing conducted by the Lapps in northern Sweden and Norway, where a nomadic existence is common reindeer grazing in Alaska is more centralized and tends rather toward permanent ranches. This is largely due to the habits of the Eskimos and to the presence in Alaska of larger natural grazing units which may be divided into individual grazing allotments each complete in itself. The nomadic habit of the Lapp requires tha

he handle his reindeer under a close-herding practice; but in Alaska, to secure the best results under a fixed allotment system, the opposite, or open herding, must generally be practiced.

CARRYING CAPACITY.

In any successful range management a consideration of grazing or carrying capacity is a matter of primary importance. By this is meant the number of stock which a range will support for a definite period of grazing without injury to the range. To attain the greatest carrying capacity, both overgrazing and unnecessary undergrazing must be avoided.

Carrying capacity estimates.—From the surveys thus far made, it appears that the range requirement for each reindeer is about 30 acres. This closely approximates the acreage required by cattle on national-forest areas in the Western States, where it runs on an average about 2 to 2½ acres per cow per month,[9] or roughly, between 20 and 30 acres a year. Some Norwegian figures give 25 to 28 acres a year in reindeer grazing. Specific observations thus far made on carrying capacity on two reindeer allotments in the vicinity of Unalakleet indicate 30 acres a year as a maximum requirement for mature animals exclusive of fawns. By including the fawns, on a basis of two fawns to one mature animal, the requirement becomes 26 acres a year. It will be borne in mind, however, that observations at Unalakleet were of necessity very general and involved largely range of the wet tundra type; more detailed work is planned to cover all important conditions.

The maximum range-carrying capacity is not realized and the acreage requirement is naturally higher under poor management. Present conditions of poor distribution of reindeer, close herding, and mishandling require large ranges. With an approach to the ideal in management, and a decrease in the present acreage requirement, a higher carrying capacity for each range unit should be developed. In determining carrying capacity, the matter of class of production must also be taken into consideration. As reindeer are now grown entirely on the range, without feeding, it is obvious that for the production of fat stock for marketing purposes a larger acreage per animal is required than for ordinary range stock.

GRAZING UNITS.

To control the number and distribution of reindeer on a given area is a fundamental requirement for effective range management. This may be attained by regulating the use of the range by a system of permits for definite grazing units, or allotments.

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[9] Jardine, James T., and Mark Anderson, Range management on the national forests: Bull. No. 790, U. S. Dept. Agr., pp. 28–29, 1919.

In allotting the range for natives or other small owners larg[e] community units rather than numerous small individual allotment[s] should be the rule. The topography of the country and the ad-vantage of handling reindeer more like cattle than sheep require[s] large range allotments for economical and efficient management[.] Allotment units should include winter, summer, and fawning range[.] It would be impracticable to make smaller subdivisions to meet th[e] requirements of owners of varying small herds, with the necessar[y] provision for seasonal grazing; such allotments would make it har[d] to control individual herds and to prevent losses.

While reindeer can be handled successfully on the range, they ar[e] not so amenable to control as are sheep. Herding must be done b[y] men on foot aided by dogs, but open herding on large ranges to insur[e] proper range use is the best method of handling a reindeer herd an[d] approximates more nearly cattle grazing. As in cattle grazing the maintenance of necessary control between allotments is more o[f] a problem than with sheep, and emphasizes the need of larger graz-ing units as against a small checkerboard system. Aside from thi[s] the cost of running large herds will be less in proportion than i[n] smaller ones, and will thus increase efficiency in control and econ-omy in production. Anticipating the filling up of the ranges t[o] their carrying capacity, small owners, particularly the Eskimos should begin promptly to organize community or cooperative herd[s] with a view to holding the necessary grazing areas.

OVERGRAZING.

Overgrazing has been defined as "grazing which, when continued one or more years, reduces the forage crop or results in an unde-sirable change in the kind of forage."[10] It may be general over an entire range unit, caused by overstocking; or it may be merely local and due to poor distribution of the stock or improper handling. In Alaska, under present practice, local overgrazing often results from both of these causes, and general overgrazing from overstocking does not occur.

What local overgrazing there is at present may be attributed mainly to the method of handling—involving close herding (Pl. XIII, Fig. 2); to holding the herd on a relatively small piece of range year after year; and in some cases close to the coast to using the same range both summer and winter. This localizing of the herds is largely due to the introduction of close herding by the Lapps and to the fact that the average native is inclined to stay near his village and the coast, where he may devote part of his time to fishing or hunting seals. Many of the natives working with the herds have not become essentially reindeer men, but remain, as for-

[10] Jardine, James T., and Mark Anderson, Op. cit., pp. 16–29.

merly, fishermen and hunters. Confinement of herds to small areas is not due to lack of range or to crowded allotments; on the contrary there is an abundance of available range. There has been little or no attention given to the matter of carrying capacity, or to the fact that with an increase in numbers of stock it becomes necessary to use more range.

One result of close herding is a cutting up of the range by the sharp hoofs of the reindeer, which in some cases causes serious injury to the forage cover. Holding the herd locally under close herding thus means localized mechanical injury to the range in addition to overgrazing. The remedy, of course, is open herding, which implies the spreading of the herd over more territory and a movement from point to point, thus materially lessening the possibilities of damage, and maintaining the recuperative power of the range as a whole. The matter of open herding is treated under the subject of Distribution and Control (p. 36).

To determine whether overgrazing is taking place, both the condition of the range and the condition of the stock must be watched. The extreme stage of overgrazing is marked by denudation, in the form of erosion and barrenness, replacing a former vegetative cover; but this form does not as yet occur in Alaska, except for small examples on old corral grounds.

Overgrazing does not necessarily imply complete destruction of the vegetative cover. On most ranges there is at least a small growth of plants of which the reindeer will eat very little except in case of necessity, and a range should not be grazed until the stock are reduced to feeding on forage of low palatability. Close grazing of this class of vegetation is an indication that the range is overgrazed, and it is soon reflected in the condition of stock, which is apt to be unsatisfactory, as shown by poorly nourished animals and particularly by a heavy infestation of parasites. Parasitism and overgrazing commonly go together, the degree of infestation often being in direct ratio to the extent of overgrazing.

The considerable area of tundra on the summer range present an important factor bearing on range utilization, particularly in the case of the wet tundra type along the coast. Owing to the soft wet ground, this class of range is much more susceptible to injury, chiefly through trampling and contamination, than the drier sites, as is plainly indicated by cut-up ground and trampled forage. In extreme examples there is a close network of stock trails between the hummocks, leaving the latter standing up in sharp relief against a background where the former vegetation has been killed or eaten. Under this condition an absence of some of the more palatable forage plants and a greater cropping of the less palatable may be noted on the hummocks themselves.

DEFERRED AND ROTATION GRAZING.

Good herding management and a correction of misuse of the rang through the practice of locally confining the herd necessitates em ployment of the principles of deferred and rotation grazing. Thi involves use of the range under a system which will permit a maxi mum of grazing and at the same time a natural reproduction of th forage crop in such way as to maintain the relation of grazing t these requirements at different stages of growth.

The following principles developed by observations of sheep an cattle grazing on the national forests of the western United States[1] will apply as well to Alaskan reindeer grazing:

(1) Removal of the herbage year after year during the early part of th growing season weakens the plants, delays the resumption of growth, advance the time of maturity, and decreases the seed production and the fertility c the seed.

(2) Under the practice of yearlong or season-long grazing, the growth of th plants and seed production are seriously interfered with. A range so use when stocked to its full capacity, finally becomes denuded.

(3) Grazing after seed maturity in no way interferes with flowerstalk pr duction. As much fertile seed is produced as where the vegetation is pr tected from grazing during the whole of the year.

(4) Deferred grazing (grazing after seed maturity) insures the planting c the seed crop and the permanent establishment of seedling plants withou sacrificing the season's forage.

(5) Deferred grazing can be applied wherever the vegetation remair palatable after seed maturity and produces a seed crop, provided ample wate facilities for stock exist or may be developed.

(6) Yearlong protection against grazing of the range favors plant growt and seed production, but does not insure the planting of the seed. Moreove it is impracticable, because of the entire loss of the forage crop.

Based on the above principles, the system of deferred and rotatio grazing aims to minimize the injury from grazing during the earl and main growth periods of the vegetation (1) by having each po tion of the range bear its share of the early grazing and (2) b protecting each portion of the range in its turn until after see maturity, so that the main forage plants will regain their vigor an reproduce either from seed or vegetatively.[12] This may be accom plished by dividing the grazing unit into three or four parts o about equal carrying capacity, in such way as to give the best contro of stock on each portion, and by rotating the time of grazing fro year to year progressively between these areas so as to give bot deferred and early grazing to each in turn.

At this time, on Alaskan ranges, deferred and rotation grazing ca best be secured on parts of the range unit where localized ove

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[11] Sampson, Arthur W., Natural revegetation of range lands based upon growth requi ments and life history of the vegetation: Journ. Agr. Research, U. S. Dept. Agr., vol. no. 2, pp. 93–148, 1914.

[12] Jardine, James T., and Mark Anderson, Op. cit., pp. 60–65.

grazing has taken place by herding away from the area until after seed maturity of the important forage plants; this can be helped eventually by salting (see p. 37). For the range unit as a whole, deferred and rotation grazing can be accomplished to an important extent simply by alternating the plan of grazing over the allotment from year to year.

EXISTING REGULATIONS AND RANGE CONTROL.

Existing regulations governing the grazing of reindeer in Alaska apply essentially to the early stages of the native industry;[13] as they were adopted prior to the building up of large herds under white ownership, they do not now fill the requirements. A new plan of regulation and control has become necessary to cover the herds under both native and white ownership and to correlate the two interests in such manner as to insure the protection of both classes. In fact such reorganization is a first essential toward building up the Alaskan reindeer industry.

Improved methods of management are vastly important but faulty basic organization may offset all the good range management that may be effected. Such basic problems as determination of ownership, industrial relationship between the native, the Lapp, and the other white men, proper supervision and organization of herds, and rights to and control of range lands, all need early consideration.

Jurisdiction over the range in Alaska does not at the present time come under any vested authority. The areas now allotted to individual reindeer herds of the Eskimos were established tentatively by the Bureau of Education. They are maintained by tolerance only and invasions of ranges are common. Legally there is no protection against encroachments upon individual allotments. Without right to control the range upon which to graze, reindeer-herd owners are much handicapped. Control of the range stands as a principal factor for consideration in handling the future reindeer industry in Alaska.

HERD MANAGEMENT.

Reindeer handling in Alaska suffers greatly from lack of application of improved modern methods. The growth in the numbers of reindeer has been very rapid, but correspondingly improved general organization, and better methods of controlling parasites and diseases have failed to keep pace with it. Consequently the industry has developed to large proportions under conditions which urgently need improvement to insure continued healthy progress. Generally,

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[13] Rules and Regulations Regarding the U. S. Reindeer Service in Alaska: Bureau of Education, Alaska Reindeer Service, U. S. Dept. Int. Whole number 466, Dec. 7, 1911.

the method of handling now employed follows the Old World practices, and these often are built up on superstitious beliefs or old customs, and have, to a large extent, apparently missed the influence of modern ideas. Reindeer grazing does not differ so greatly from other live-stock handling that the same principles of management are not generally applicable. The improved practices in handling live stock employed in the Western States apply equally in general principles to the handling of reindeer in Alaska.

Among other things, the Eskimo herd owners greatly need corrals and cabins (Pl. XIV, Fig. 2) on the grazing areas to promote better herd management. Lack of proper corralling facilities is preventing the accurate marking of stock and the making of counts and ownership records of many of the native herds, some of which have not been counted for several years. Often in the larger bands only a part of the fawn crop is being successfully marked each year, and unmarked yearlings are commonly noted in the herds. Aside from entailing confusion in ownership and leaving an opening for "rustling," this lack of corrals otherwise impedes proper supervision.

Without cabins on the winter range, in many cases the reindeer are held on the same ground along the coast both summer and winter. This, of course, damages the range and jeopardizes the herd when the snow crusts over. Proper winter range lies in the hills back of the coast, where there are protected areas with an abundance of reindeer moss. Consequently, winter quarters should be established away from the coast villages, and this requires the construction of cabins in the hills on the seasonable ranges.

Unless the reindeer industry is put on a good commercial basis, there will be little incentive for investment in stock, and the herds will be of value only for the owner's individual needs and for a very limited local sale. Consequently, if its greatest development is to be attained, it will be necessary for white interests with capital and initiative to take a leading part. If development of the industry should be confined mainly to the natives, progress will be relatively slow, since, unaided, they have not the ability, knowledge, or means to develop it.

SUPERVISION OF HERDS.

In any event, better supervision of the native herds is necessary to care properly for them. Such care and protection is important not only in view of the natives' food and clothing requirements, but also because of the need for meat production to aid in fostering local white enterprises in the Territory.

The native herds are scattered throughout the present coast range on all grazing units, irrespective of white or native occupancy. Thus reindeer of both natives and whites often graze cooperatively on the

same range, and in such instances all the animals come under white management. Except where cared for in a white man's herd, the Eskimo reindeer are generally rather badly managed because of the improper methods employed and the lack of trained supervision. The teachers at the Eskimo schools maintained by the Bureau of Education are doing all they can to supervise the management of the herds of the people at their stations, but they are not skilled in animal husbandry, and their other duties occupy their time. The assistance of a small organized corps of trained white men to look after the native herds and supervise their development along improved practical lines is urgently needed.

COMMUNITY HERDS.

The organization of herds on a cooperative basis, as proposed and recently initiated by the Bureau of Education, will not only secure proper and definite allotments of range but will promote more effective management of both herds and ranges. Such organizations among native owners will make possible the employment of the best reindeer men for herding and prevent interference and meddling by others. It will make possible uniformity in distribution of herders between bands, establish adequate and just remuneration for them, and eliminate the inefficient herder who could put in his time to better advantage in fishing and hunting. It will result also in the adoption of one distinctive earmark or brand for the combined herd, and in a centralization of herd management, either in a white superintendency or in an advisory board of the leading natives under white supervision.

In larger herds under the cooperative plan herd management will be much simplified. Gain and loss in the herd will be prorated among the individual owners, and it will be easier to guard against "rustling," which may grow to serious proportions. The supervision of native holdings by the Government also will be greatly simplified and made more effective.

SIZE OF HERDS.

In Alaska, reindeer are now run in herds of from less than 400 up to 5,000 head, and in one case 8,000. While the future tendency will be toward the larger herds, under existing conditions it appears to be preferable, for the present at least, that the Eskimo reindeer be run in herds of medium size. In the absence of proper corrals, in order to insure less complicated handling, particularly for marking and counting, these should not be larger than 1,000 to 1,500 head each.

Where a cooperative organization includes several small bands or herds, this should not necessarily imply uniting all of them in one

band on the range. When two or more large bands are under one ownership, they should be maintained so far as practicable in separate herds on distinct grazing areas or on separate portions of a large unit. On the other hand, when two or more small bands are held by the same owner they can usually be combined to considerable advantage, provided they do not make the one herd too large.

The greatest number of reindeer that may be run economically in one band under present methods of handling has not yet been determined. It may be pointed out that with the present distribution within a grazing unit, it may be for the best interests of both the range and the animals to run two or more medium-sized bands than one very large one.

The following points should be carefully considered: A very large band, unless very openly herded, will do proportionately more injury to the range than a smaller band. On the other hand, other things being equal, it may cost as much to herd the small band as a medium-sized one. A large mixed herd may be run probably without undue injury to the range if before fawning time the does can be successfully segregated from the bucks, steers, and yearlings, and during the early part of the season the two groups run separately.

DISTRIBUTION AND CONTROL WITHIN UNIT.

Grazing units having been established and definite numbers of stock allotted to each, the next problem will be to realize the best use of the forage within each allotment. This requires such control of the stock within the allotted grazing area as to bring about full and uniform grazing. Steps to be taken to this end include herding, salting, and the construction of needed range improvements, such as fences and cabins.

Herding.—Open herding is the best method of handling reindeer to avoid damage to the range and to secure the best results in the herd. In close herding, as frequently practiced in Alaska, the stock is held closely banded together at all times, whereas in open herding the animals are allowed to graze spread out on the range. In the latter case herding consists chiefly in making a big circle around the band each day, without disturbing it, but working in the few strays that get too far away from the outer grazing circle.

While permitting the herd to spread loosely on the range and involving less handling or disturbance, open herding must not be thought of as implying lax herding, in the sense of turning the animals loose to wander over the country at will, to be herded only at intervals. Proper open herding requires constant attention, but with as little disturbance of the herd as possible, thereby maintaining a more natural and wide-spread grazing on the particular range


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FIG. 1.—REINDEER HERDERS ON ST. LAWRENCE ISLAND.

These Eskimos are enthusiastic reindeer men and are eager to learn all they can about the reindeer business.


B22652

FIG. 2.—HERDER'S CABIN.

Chief Lapp herder and Eskimo assistant in front of cabin on the Egavik range. Herd dogs in the foreground.

area used. Unless the herd is constantly watched material losses are sure to result through straying.

Reindeer herding is now done entirely on foot, mainly by natives and Lapps, commonly aided by dogs (Pl. XIV, Fig. 1). One or two herders go out each day from a central camp to watch the herd, sometimes remaining out over night. The herd dogs are generally of small size and compare quite unfavorably with a good cattle or sheep dog. Improvement in the breed of reindeer dogs is desirable and would aid greatly in attaining better herding.

For bands numbering on the average from 1,000 to 1,500 head, usually three herders are employed, with extra help during the marking season. Herds numbering from 2,000 to 5,000 require a herd superintendent, a chief herder, and three good herders during the greater part of the year, with extra help to insure fast work at marking and butchering time, usually 20 or 25 men for a few days.

Salting.—Salting, said to represent the best herder the cattleman has, is considered as offering the greatest possibilities for maintaining a proper distribution of cattle on the range, and it is believed that it may likewise be developed as a major factor in controlling reindeer grazing. By its use, considerable improvement in the distribution of stock and utilization of range is made possible. Reindeer salting will be similar to salting cattle and the same principles should apply.

Reindeer are very fond of salt, and when held along the coast they get it during the summer season by drinking the sea water or licking up the deposits on the beach. Along with the fly pest, this undoubtedly serves as an important factor in urging them to the coast during the summer months.

The salting now being done on a small scale in Alaska by a few of the white reindeer owners is with crushed rock salt. This is placed on the range usually by scattering handfuls on rocky ground. On one allotment in the summer of 1921 a small amount of experimental salting was begun, using both the crushed rock salt and the block salt. The owner reported that so far he has found that the reindeer are very fond of the crushed salt, but that they scarcely touch the block salt. This may be significant as indicating that it may be found necessary to use crushed rock salt exclusively for reindeer. Salt in both forms will be thoroughly tried out in the experimental projects undertaken by the Biological Survey. If found equally acceptable to the animals, block salt would be preferable as being more convenient to handle and transport. Crushed rock salt would probably require troughs to use it in an economical manner.

Fencing—Open herding and necessary control between adjoining grazing units, particularly on the summer range, may be facilitated

by the construction of short division fences in many localitie Fencing at this time, however, should not be considered a major re quirement in reindeer grazing, but more as an expedient that may b resorted to in some places to obtain better stock control. In the mo heavily timbered ranges of the interior, fencing no doubt will prov more of a necessity, not only for control but for protection as wel

The greatest use of fencing is to insure against mixing of herc in certain cases on adjoining allotments, especially where there a no natural barriers along the boundary lines. As the ranges becom fully stocked the need for such fences will be more and more evide and they will be a necessity in some cases if allotments are to be full utilized and if herds are to be prevented from mixing along th boundaries of adjoining allotments. In the absence of fencing th tendency will be to confine the herd as much as possible to the inne portions of the allotment, thus leaving a belt of unutilized range alon the boundary lines, resulting in a material loss of range. Fencin along such boundaries would permit grazing up to the allotment lin and thus eliminate loss. The mixing of herds involves much lab and time in corralling and separating the animals and often resul in injury to the stock as well as to the range where the herds a closely held. Absence of fencing will tend to increase the size c allotments to make up for the ungrazed borders.

The problem of control between grazing units may be greatl lessened by careful selection of allotment boundaries, careful herc ing, and perfection of systematic range management. In locatin allotment boundaries, advantage should be taken of such natur barriers as streams, prominent ridges, and other major topographi features.

Fencing within the grazing unit may later be of value as an aid i the following respects. To better control deferred and rotation gra ing; to segregate breeding stock from nonbreeding stock; to contr stock in timbered sections; to maintain holding pastures for stoc during a round-up, either in connection with cold storage plants c with marking and separating corrals.

Careful herding at all times is of prime importance to prevent mi ing, but cooperative arrangements between owners of herds on adjoi ing allotments should evolve a system of rotation grazing whereb each allotment area may be almost fully utilized by having onl one herd near the border at any time. The practicability of fencin any particular allotment should be considered from the viewpoint c ground site, availability of material, and expense of construction a related to maintenance cost of the herd as a whole. Fencing even a this time will not take the place of efficient herding if it can be pro cured.

Construction of cabins.—Reindeer herding deals with large acreages, a country of sparse settlement and poor transportation facilities, and traveling over the range on foot, usually under adverse conditions. Consequently there is great need for the erection of shelters or cabins for the herders here and there on the range (see Pl. XIV, Fig. 2). At least three main cabins are needed on the average allotment—one headquarters cabin on the summer range, one headquarters cabin on the winter range, and one cabin on the fawning grounds. In addition to these, and depending upon the size and character of the allotment, the construction of several subsidiary cabins or shelters at strategic points over the range will facilitate the work of moving herds about the range and handling them with less confinement and disturbance. In some instances, tents may suffice, but a permanent shelter is preferable, since this will be more comfortable and permit the storage of necessary supplies at favorable periods in the year and save much labor where transportation is difficult.

The construction of necessary cabins is not difficult in timbered sections of the country; but where there is no timber, as over the major portion of Seward Peninsula and along the Arctic coast, the problems of material for cabins, of available fuel, and of transportation are serious, especially so on treeless winter ranges. Material is readily available for the summer on the coast of Bering Sea in the form of beach driftwood and of lumber brought in in a few instances by boat for building purposes, while driftwood, willows, and natural lignite serve for fuel.

Much of the fuel and building material for cabins on the winter ranges of the Seward Peninsula must be transported into the hills from the coast. In some cases this will prove difficult, and in a number of instances it is this very difficulty of building a new winter headquarters that is holding the herd on old and fed-out ground when it should move on to new range. However, while transportation of material to desirable winter-range sites on the Seward Peninsula or elsewhere may not be attempted under present conditions, it undoubtedly will be in the future through large holdings under individual or cooperative management.

GRADING UP THE STOCK.

It is apparent that little or no thought has been given in Alaska to the proper breeding of reindeer. Exchange of blood between herds has been more a matter of accident than design. It is especially important that more attention be paid to the selection of herd bucks. At present there are too many undesirable small bucks doing service, and in too many cases the larger animals, which should be heading the herds, are castrated and later killed to supply the meat demand.

Not more than 5 bucks are necessary for 100 does, and records indicate that even less than this number may suffice. In one instance, a ratio of only 1 to 30 was maintained with successful results, and in another case the ratio was 1 to 44. All bucks not needed for breeding purposes should be castrated and grown as steers (Pl. XV, Fig. 1).

The female side of the better breeds question must also be considered. Old does are either unproductive or have weak fawns, so that it is highly desirable to cull out a percentage of them each year. These animals should be separated or marked sufficiently early in the year for the unproductive ones to be easily identified, and they may be profitably butchered either before or soon after the rutting period. In addition to the old does, all stunted, sickly, or otherwise undesirable animals should be disposed of.

In other breeds of domesticated animals the present cry is to eliminate the scrub. By applying this practice just as rigorously in the reindeer business, and by introducing the practice of selective breeding, the first and most important step will have been taken toward establishing a better grade of stock.

Crossing with caribou.—Experiments are being planned to introduce caribou bulls into a herd of reindeer in which the reindeer bucks will first be castrated. The woodland caribou is a much larger animal than the reindeer, and dressed weights of over 300 pounds are common, while the average dressed weight of reindeer steers is only 150 pounds. The mixture of caribou blood will undoubtedly have a decided effect in increasing the weight of the animals. In addition to the introduction of the large caribou bulls, a carefully conducted program will be carried out of permitting only the best reindeer stock to breed, the undesirable or scrub males and females being weeded out. It is believed that reindeer may be brought up to double their present weight and that this program of improved breeding can be generally introduced throughout Alaskan herds. It is planned to conduct the experiment on an island where there is only one herd. This will eliminate the chance of error by the intermingling of stray animals. It may be stated that caribou mix readily with reindeer and they are constantly being seen in the herds. Unfortunately this is generally late in the season after rutting time, and besides this the caribou are wild and do not remain for long periods in the herd. These difficulties will be eliminated in the proposed experiment, which should mean much to the reindeer industry.

HANDLING THE HERDS.

ROUND-UPS.

Numerous round-ups (Pl. XV, Fig. 2) for trivial reasons and much driving of the reindeer during round-ups and on the range result in injury to both herd and range and in loss in weight of the

B20465

FIG. 1.—REINDEER STEER.

A well-built blocky type of meat-producing animal. Such reindeer are less numerous in the herds than could be desired, but by selection of breeding stock they can be made predominant and greatly to add to the meat output. (Photographed September 26, 1920.)

B20513

FIG. 2.—ROUNDED-UP HERD.

Photographed at Norton Sound in the summer of 1920. When reindeer are rounded up, even in the open, they crowd into a compact mass like a herd of sheep.

B22614

FIG. 1.—A WINTER ROUND-UP.

Eskimo herd on the winter range on Golsova River, February 25, 1921.

B22688

FIG. 2.—HERDING TOWARD THE CORRAL.

By establishing the corral just over the brow of a hill, as in this case, the reindeer find themselves practically inside before they see it. Wing fences of brush or other material running out from the corral guide them to the entrance.

animals, and must be avoided if the best results for the herd are to be obtained. Where there is no central management and lack of concerted action in handling herds among the various owners, the tendency is for frequent round-ups throughout the year for the convenience of individual owners, without regard to the common interest or the welfare of the herd as a whole.

In a systematic business management of the herd, round-ups will be reduced to a minimum and the necessary handling of the animals planned to fall as far as possible into three main periods: (1) a spring round-up for counting, marking, and castration of fawns; (2) a fall round-up for cutting out steers for market; and (3) a winter round-up for separating breeding from nonbreeding animals. Round-ups between these periods, unless absolutely necessary, should be avoided.

In fixing the round-up periods consideration should be given to the time of year that the herd may be handled with least injury. The spring round-up should take place early in June prior to the fly season, which begins toward the end of the month. The fall round-up should be during the period that the animals are in best condition for butchering, and when handling is practicable; this is generally at the close of the summer grazing and after the rutting period. The winter round-up (Pl. XVI, Fig. 1) should be in the fore part of the season, since toward the end of winter the females are heavy with fawn and consequently should not be disturbed. When a round-up is to take place, all interested parties should be duly notified. If an individual fails to avail himself of the opportunity to cut out or otherwise handle his stock, he should not be permitted to have a special round-up later for individual work.

CORRALS.

The corral method generally employed at present is to rope in a crude brush or pole inclosure on the open range. This usually involves handling the herd for a long period, often requiring two or three weeks, and as a general rule results in considerable losses of animals injured or killed outright. If these losses are to be eliminated, roping must be reduced to a minimum and as much of the handling as possible done in a corral arranged with separating pens and chutes. In any case, greater care must be taken in handling the animals.

On most allotments two corrals are used, one on the summer and another on the winter range. The main corral is on the summer range and is usually built near or on the beach, ordinarily of driftwood, brush, and green poles, or sometimes lumber, wire, and burlap. On the winter range a brush corral is usually constructed. The

summer corral is used largely for marking, castrating, and counting and the winter corral for separating purposes and for cutting ou animals for slaughter.

Many of the bad features under the present methods of corrallin can be overcome by building proper chutes connected with the cor rals. The time now taken in separating a herd by the roping metho is much too long. In one case, a herd was worked 9 hours on eac of two days, with 5 to 6 men roping, and then only 234 reindee were handled. In another case during the winter a herd was hel in a corral during severe weather and starved for 48 hours. Whe to this period the collecting and driving of the herd is added it ca be readily seen that much injury must have resulted to the animal

If reindeer are handled in too small an inclosure, the warmth o their bodies soon causes the surface of the ground to thaw and thi later freezes and becomes icy, resulting in many injuries to th animals from slipping and falling. If there are sticks and stump projecting through the snow, as is frequently the case, ribs and leg are sometimes broken. When the corral is too small some of th animals may be trampled, and this results in many losses. In th second case mentioned above, of 1,443 deer handled during th 48-hour period, 11 deer were accidentally killed and a great man injured. Under present methods the owners regard these losses a an unavoidable part of a round-up. With proper corrals, howeve such losses may be almost entirely prevented.

A diagram of a highly successful type of corral in use at Buck land River, Alaska, for overcoming the present drawbacks i handling, is shown in Figure 2. In a corral of this type used in th Kotzebue Sound district during the marking season of 1921, a larg herd was put through in 10½ hours and a total of 1,680 faw marked. In another case, at Golovin, 1,250 animals were marke (ears notched and buttoned) in 14¾ hours. The corral illustrated i exceptionally large, being made to hold 10,000 reindeer. A corr of about half this capacity should suffice for the average Alaska herd.

The separating pens, or pockets, on either side of the entrance t the connecting chute form a special feature of this type of corra By their use sections of a milling herd may be detached and p through the chute as needed. The pockets are merely partitioned o from the corral by "hooks," made in three sections at angles, whic keep the detached part of the herd from rejoining the others, b turning the leaders away from the entrance, so that the animals mi in the pocket until the excitement due to imprisonment has subside Without the hooks it would be almost impossible to handle the la animals in the corral and the leaders would become wild and refu

to be driven. Two hooks are employed, for the reason that the milling animals tend to reverse the direction of their movements when they approach a pocket from which they have succeeded in escaping on previous occasions, and then, not recognizing the danger of entering the other, they are driven into it and operations are thus facilitated.

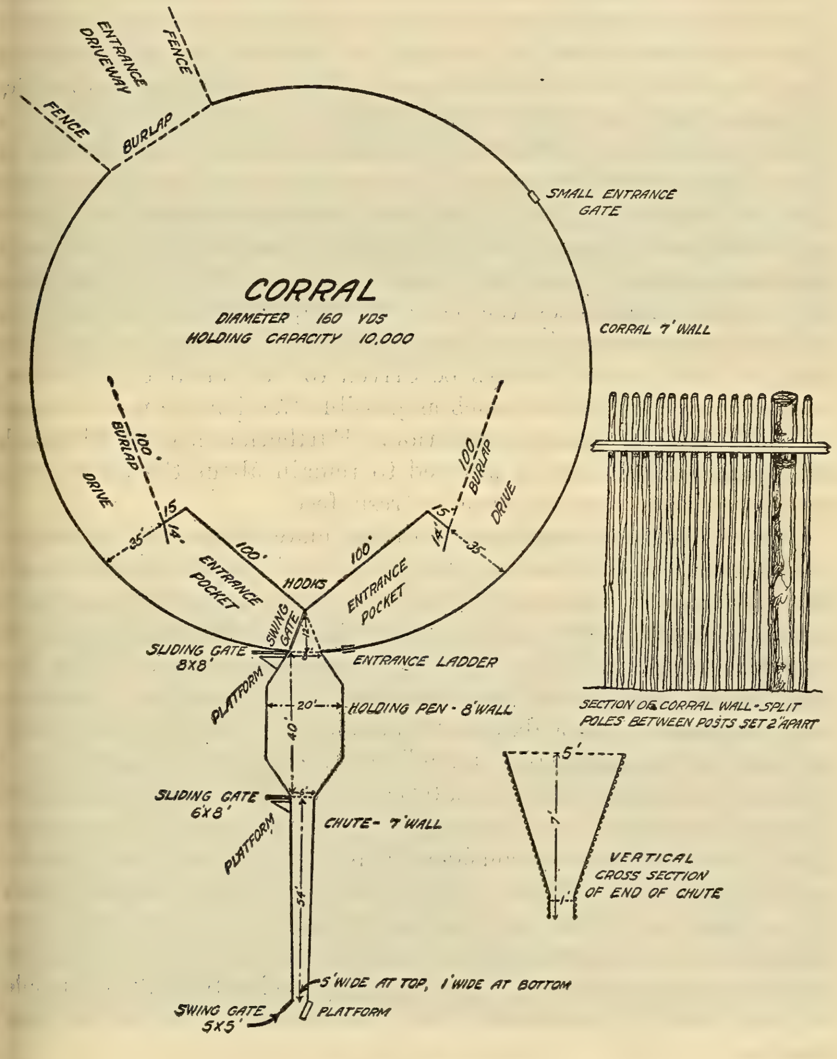


FIG. 2.—Diagram of improved type of corral for handling reindeer, chiefly for counting and branding; constructed entirely of split poles. The reindeer are driven into the main corral between long side wings, and sections of the herd are detached as needed by means of the separating pens, gates, and chute. A further improvement would consist of a small corral at the end of the chute, where all animals are handled, to trap any that might evade the herders stationed at the swing gate.

Men are stationed at the various platforms and gates, two on the platform at the end of the chute (Pl. XVII, Fig. 2), to hold back the reindeer by catching their horns, in order to prevent overcrowding at the exit. The chief herder is usually the one stationed at the swing gate, and he decides what disposition is to be made of each animal as it passes.

As a rule the Lapps build the corral just over the brow of a hill, so that the reindeer do not see it until they are practically inside. The animals are driven in through the entrance driveway between long wing fences, which in some cases extend out a quarter of a mile or more on each side. (Pl. XVI, Fig. 2.)

The present slow system of corralling often results in keeping a herd in the immediate vicinity of the corral for long periods, in some cases for weeks at a time. This causes undue trampling and damage to the near-by range and exposes the animals to grazing on contaminated ground, where they pick up large numbers of parasites, and further emphasizes the need for improvement. If for unavoidable reasons the improvement advocated can not be made at once, the herd should always be driven to the corral by the same route, in order to limit as much as possible the damage to the range and the danger of parasitic infection. Furthermore, when liberated the animals should not be allowed to remain about the corral, but should be driven away at once to fresh feed.

Choice of site and selection of building material are two important considerations in constructing the main corral on the summer range. It is particularly important to build the corral in a dry place, as it is readily apparent that a herd may be handled more efficiently and with less danger of injury here than on wet ground. When the corral is on wet ground, the tramping of the "milling" animals soon converts it into a dangerous mud hole. The best sites along the coast are on sandy spits immediately adjoining the beach.

In the selection of building material, it should be kept in mind that a closely constructed corral fence or wall is preferable to an open one. There is the possibility of considerable injury to animals in an openly constructed corral. When pushed and frightened, reindeer often try to break out of the inclosure at any point they can readily see through; and, in the attempt, may get their legs or horns caught and, as often happens, broken. Consequently a closely built split-pole or board corral is preferable to one constructed of wire or of open paneling.

METHOD OF ROPING.

The lasso, or lariat, used in Alaska differs from the rope commonly seen in the Western States. Reindeer men prefer a flexible cotton rope about one-fourth inch in diameter. The eye is made from a piece of reindeer horn, and is of considerable weight. The entire

B22602

FIG. 1.—ROPING REINDEER IN WINTER CORRAL.

Herds may be handled successfully even in cold weather. This photograph made on January 10, 1921, when the thermometer was between 30° and 40° (F.) below zero.

B1901M

FIG. 2.—END OF CHUTE LEADING OUT OF CORRAL.

The walls are 7 feet high, and 5 feet apart at the top. The floor space narrows toward the exit, until it is only 1 foot wide (see diagram in text, Figure 2). Under this method of construction crowding of reindeer trying to escape can be prevented by herders stationed on either side to hold them back by catching their horns.

rope is gathered up into a number of small coils, and thrown at the deer's antlers with the motion used in throwing a stone. The roper does not whirl a single loop and throw the rope in cowboy fashion, but throws the lasso so that it hits the horns and entangles them. The thrower does not know whether he will catch one or both horns, but expects that the loops will get caught on one or more of the numerous points on the antlers. Roping reindeer (Pl. XVII, Fig. 1) is much easier than roping cattle or horses, where either the feet or head must be accurately encircled. Reindeer are caught by the feet only by accident.

A form of injury that often occurs in roping, but to which the reindeer owners appear to pay little attention, is to the growing horns. These are very vascular and soft, and are easily hurt. Serious hemorrhages are apt to occur, and harmful bacteria may gain entrance where the velvet of the horns has been rubbed or torn off. For this reason it is desirable to avoid roping the older animals, at least, until the velvet has "set."

EAR MARKING.

Ownership in reindeer is commonly indicated by ear marking. Usually this is done by cutting off the tip or notching one or both ears, and one or two herd owners use a metal ear tag or button in addition to cutting. Each individual owner has a different earmark, and often separate marks are used among the various members of the same family, particularly in the case of the Eskimos—the father, the mother, the sons, and the daughters each having his or her individual mark. Constant trading and bartering of deer among the natives results in the earmarks being continually so changed that at times the ears are almost entirely cut off. Moreover, in the absence of provision for the registry of these marks, there is often considerable confusion as to the ownership of the animals, and petty "rustling" is frequently reported.

The fawns in the majority of herds in Alaska are now earmarked like their mothers. Individual reindeer owners pick each fawn as belonging to this or that mother and mark it accordingly. In a small herd this may be successfully done, but in a large community herd, especially where there are many owners, marking according to the mothers does not work out very well. In a "milling" herd especially, fawns may not follow their mothers. Thus it may often be only a guess as to ownership in the picking of any particular fawn, and a large margin of uncertainty must exist in the selections made. Consequently, there is the possibility of injustice in marking, particularly in the native herds, since it is evident that the individual owner having the greatest assurance and aggressiveness is in a position to get more than his share of fawns.

The solution is to adopt the plan of cooperative herds proposed by the Bureau of Education, each under a single brand, in which the owner has a percentage holding. Under this arrangement each owner will be given his pro rata share of the total fawn crop, based on the total number of his does in the herd; and the burden of loss and expense of running the herd, as well as the increase, will be proportionately divided among all the owners.

Marking all fawns alike in a herd under the percentage ownership system is to the best interests of the herd. Marking fawns according to the mother involves the use of the old roping method and handling the herd in a corral for long periods, resulting usually in injury to the animals. On the other hand, marking by percentage involves the use of the chute instead of roping, and, in addition to speeding up operations, insures good results and largely eliminates injury.

BRANDING.

Trimming or notching the ears of a reindeer is unsatisfactory as a means of identification, and, as previously mentioned, such a mark may be altered with comparative ease. A brand on the skin, being less easily changed, is preferable. To try out this method, two yearlings were branded on April 30, 1921, at the Unalakleet station, with a hot iron, one on the jaw and the other on the hip. The hair was clipped, and the brand in the form of a U was applied lightly. The lesions healed rapidly and the hair began to grow very soon. In August of the same year, when the animals were brought back to the station from summer grazing, it was found that the jaw brand had been a complete success, a clear white U being plainly visible (Pl. XVIII, Fig. 1). The brand applied to the hip did not show quite so plainly, but was a sufficient mark for practical purposes.

Fourteen other animals were branded during the month of August, 1921, for later observation. These were all branded on the hip, since this promises to be the best location for branding for easy observation when the animals are on the range or are being driven. In these cases the hair was not clipped. In one or two instances, owing to the heavy growth of hair, the brand did not come quite clear and had to be retouched. This, of course, is bad practice. With a little more experience it is felt certain that the brand can be applied successfully at one operation.

Previous attempts at branding in Alaska had not been successful, probably because too much force was used in applying the iron, thus driving it through the skin. Some animals are reported to have died following the operation. Reindeer skin, as is the case with all heavily coated animals, is very soft and thin, and consequently branding must be done deliberately and carefully.

DEHORNING.

It has been remarked that the large growth of horn which is com-
ion to all reindeer must be a heavy drain on the system, and that the horns could be eliminated the body weight of the animal might icrease. Experiments in dehorning were made on two yearling eindeer which were being kept at the Unalakleet station. About 0 days after the horns had dropped the velvet had grown to a idth of about one-fourth inch surrounding the horn core. After ightly moistening, sodium hydrate was rubbed onto this new rowth. Only one of the horns on each animal was treated. rowth stopped at once and a scab covered the area. In about iree weeks the scab began to lift at one corner and in a few days ie treated horn was growing just as rapidly as the untreated one. hat considerable injury had been done to the horn was evinced y the fact that a large white area appeared on the velvet. Strange say, the injury appeared to stimulate the growth as well, and by ie latter part of August it was found that the treated horn was iuch larger than the untreated one. (This is illustrated in Pl. VIII, Fig. 2.) It had been suggested that the proper time to onduct a dehorning experiment is when the fawns are newly born; it unfortunately, it is not safe to handle the fawns at that time; onsequently the outlook as regards dehorning does not seem romising.

CASTRATION.

The Lapp method of castration, which consists of crushing the sticles, was introduced into Alaska at the time the reindeer were rst imported. This method, still followed in some districts, is irbarous and often ineffective and should be stopped as soon as ossible. The method used for other kinds of domesticated stock, onsisting in opening the scrotum, or bag, with a knife, severing ie cord, and removing the testicles, is proper for reindeer as well. No instruments other than the knife are required if the operation done on the fawn soon after birth, but this is not good practice. ith the older animals, however, serious hemorrhage is apt to fol- w unless an instrument such as the emasculator is used to sever the ord. It is gratifying to record the fact that the use of the emas- ilator by the Biological Survey in 1921 was at once accepted by erd owners as an improvement and that its use has spread rapidly. ot only are the natives using it under the direction of officials of e Bureau of Education, but the leading Lapps have expressed emselves as in favor of the method. During the past season a rge number of animals in most of the principal herds have been ccessfully castrated with the emasculator, so that it is now probably ily a question of time until all herd owners will have adopted its e.

The time for castration should be governed by the weather, as i is unwise to undertake it when the weather is hot and flies ar abundant. The proper time to operate on fawns or yearlings i when green food is available and before the hot weather and th flies appear. As it is unsafe to rope or handle adult reindeer whe the horns are in the velvet, on account of danger of injury, castra tion of the older animals should take place either early in the sprin before the horns are grown, although they are harder to handle a this time, or else after the velvet has "set," which is just befor rutting, or about August 20.

Cleanliness in the operation is important to avoid infection, an disinfectants should be used to keep the hands and the instrument clean. The operator should not have to handle the animals, bu they should be thrown and held as he directs.

FAWNING.

The average period of gestation in reindeer is 7 months and days, so that the first fawns generally appear about April 10. I 1920 and 1921 the first signs of rutting were noticed the latter par of August, and it continued into October (Pl. XIX, Fig. 1). Dur ing rutting time the herd should be placed in the best pasture avail able and should be very little disturbed, and during the latter par of the winter the does should be kept as quiet as possible for a least two months before fawning, in order to avoid accidents.

In selecting areas to be used by reindeer during the fawning pe riod, at least two requirements must be borne in mind, namel ample green feed, so that the does will produce sufficient milk fo the fawns, and a site giving protection against severe storms. good fawning range should have as good natural protection as th topography and surface cover will allow, particularly in the wa of coves and hollows and available patches of protecting brush o timber. Low altitudes with favorable exposures for the earl growth of vegetation afford the most desirable fawning grounds.

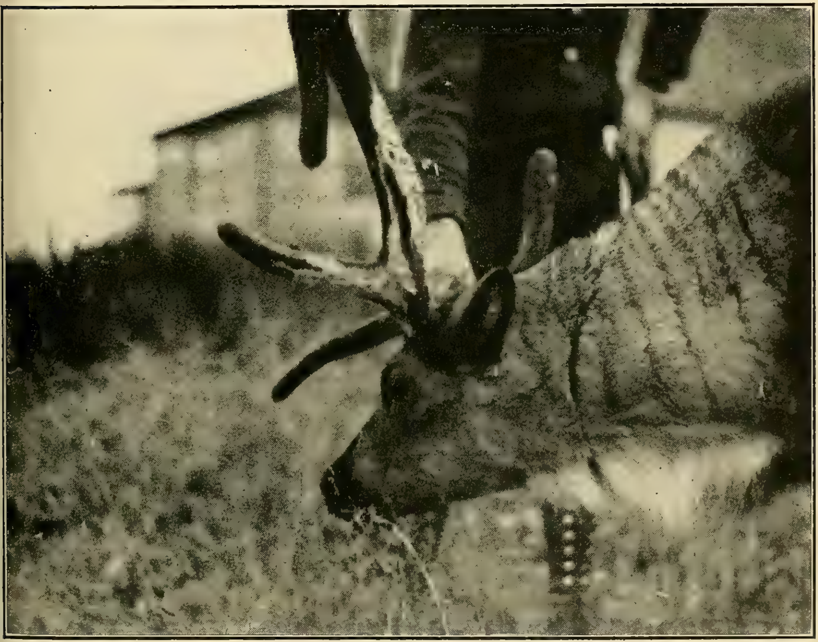
Along the coast of Alaska fawning usually takes place on som portion of the summer range, either on exposed flats immediatel along the beach or on the south slopes of the low hills adjoining it The snow leaves these areas earliest, exposing patches of bare tundra where the first fresh growth appears, thus making available th succulent green feed necessary for the does during fawning (Pl XIX, Fig. 2). This early growth usually consists of young shoot or flowering stalks of the small cotton sedge (*Eriophorum callitrix* which appear abundantly on the tundra, and its green blades als are found here and there on protected spots.

A definite fawning ground should be established and used o each reindeer allotment, both from the standpoint of best care o

B22705

FIG. 1.—REINDEER BRANDED ON JAW WITH A "U."

A means of marking reindeer is much needed to take the place of the present practice, which frequently results in badly mutilated ears. Branding is still in the experimental stage, but the success of the few experiments is most encouraging.



B22715

FIG. 2.—A DEHORNING EXPERIMENT.

One horn of the animal pictured was treated with caustic about four months before to try and arrest its growth. A white patch in the velvet shows that some injury was done to the horn cells, but the caustic also stimulated their growth. The treated horn became much larger than the untreated one, which can be seen on the opposite side. The outlook for dehorning reindeer is not promising.

B22748

FIG. 1.—RUTTING REINDEER BUCK.

The flashing eye, thickened neck, line along flanks, and manner of holding head to one side are characteristic. The bucks look more dangerous than they really are, though they often fight among themselves.

B20521

FIG. 2.—REINDEER DOE AND FAWN.

The mother is licking her newly born offspring, which lies in the snow. The fawns are very hardy from the first and very few die at fawning time. They are able to follow their mother immediately after birth. (Photograph by Lomen.)

the range and best results with the animals. Under present methods, in addition to being used as fawning ground in spring, the range is often grazed continually during the summer season, and this subjects it to becoming depleted through over-utilization. Setting aside a separate area for use only during fawning would insure a forage crop each spring and plenty of the best available fresh green food for the does at the time.

The practice of weaning fawns is not followed in Alaska, and many of them are still being suckled when the next fawn arrives. This is not only a double drain on the doe, but also is detrimental to the new fawn. Consequently herd owners should separate yearlings, along with bucks and steers, from the does prior to fawning. One Alaskan owner has already put this into effect. It is an old Lapp practice which was discontinued by them when they came to Alaska and should be revived.

FEEDING EXPERIMENTS.

Feeding reindeer has been tried out on a small scale. In 1920 two fawns were brought to the Unalakleet station and kept inside a small yard and shed for a period of six months. During this time they were fed the following: Reindeer moss, 3,000 pounds; wild native hay, 1,500 pounds; and assorted meal, 200 pounds. The meal, which was such as could be purchased at any village store, consisted of rolled oats, cornmeal, oatmeal, farina, graham flour, wheat flour, and hominy. The only item on this list which the fawns refused to eat was the hominy, which was apparently too hard for their teeth, and after attempting to crack the kernels a few times, they gave it up. In addition, apple and potato peelings and similar scraps were fed and much relished by the animals. The above test indicates that reindeer may be housed and domesticated like other animals, although the pair experimented with were not kept entirely away from reindeer moss.

Reindeer are not careful feeders like the horse. They resemble cattle in this respect and do not object to food which has been handled or, in some cases, even trampled. There is little difficulty, therefore, in getting them accustomed to a new food. They may refuse it at first if it looks or smells strange, but this can be overcome by forcibly placing some of it in their mouths, and if it is found palatable they will soon take it freely.

Reindeer respond promptly to a good food supply. A correspondent on the lower Yukon acquired a herd which had been badly managed, and the animals were in very poor physical condition. He put them on good pasture, and though they improved to some extent, the average dressed weight of the steers was only 150 pounds

for the first season. The second year, however, showed a marked improvement, and the dressed weight rose to from 175 to 200 pounds.

Another instance might be cited of a herd on Norton Sound. In 1920, through too much close herding and corralling, a herd had run down to such a point that some of the animals were dying from parasitism, which always follows prolonged close herding. The dressed weight of steers ran very little over 150 pounds, though few weights were taken. It was recommended to the owners that they change their system so that the reindeer would have more freedom and an opportunity for fresh pasturage. The result was apparent in one summer, and in 1921 the animals which were killed for meat were in splendid condition; one weighed 204 pounds, two 199, and another 156. In each case the skin, head, and legs had been removed. From the above it is evident that reindeer need only good range and careful handling greatly to increase the returns in yield of meat.

For centuries the Lapps have been driving reindeer and feeding them on moss alone and during recent years in Alaska this has also been done. The practice in use heretofore has been to drive the animals until they show signs of exhaustion and then turn them loose and take fresh ones. This does not appear to be good practice, as a sled deer is a comparatively long-lived animal and deserving of better treatment. No animal can be expected to perform steady and arduous work on poor food. It can be predicted with confidence that if reindeer were given grain in some form together with the moss, they would endure far more hardship without losing so much flesh and strength. Further experiments are necessary to settle these points fully and to determine the facts as to the possible use of the reindeer as a light draft animal.

BREAKING SLED REINDEER.

Breaking reindeer for driving, as observed in the Unalakleet district, is done in the winter and the method is rather crude and rough. A reindeer is roped, haltered, half dragged and half driven to a tree or post and tied there. It is usually left tied for a couple of days, until it is sufficiently starved to follow a man. Then it is led to a moss patch and tethered with a long rope. When first harnessed, the deer is tied short, so that it can not strike with its fore feet. Long lines are attached to the halter for driving, and at first the Lapps let the deer drag them about on skis. Sometimes they hitch the animal to a log, and finally it is harnessed to a sled by a long single rope.

The driver starts off by letting the animal gallop as fast as it can, and by jerking one rein or the other a course is steered. An animal soon becomes exhausted and lies down; then it rises and starts off rapidly, but after a short course it becomes exhausted once more.

When the driver thinks it has had enough he tethers it out again for feed and rest.

As reindeer get no other food than moss when they are being worked, their strength soon diminishes, and it is the opinion that they do no more and no less, comparatively, than an ox would do under similar conditions if fed on nothing but hay. Well-broken animals are not very plentiful in Alaska, and many reindeer men prefer to drive dogs.

Many difficulties are encountered in using reindeer for sled animals, and one especially is through meeting dog teams on the trail. In the Unalakleet district only the Lapps drive reindeer (Pl. XX, Fig. 1), while the Eskimos invariably use dogs. Almost everyone who has driven reindeer has had fights with dogs or has had his deer bitten or killed.

Added to this menace is the difficulty of finding moss within convenient reach of the villages, where the deer may be tethered. The most satisfactory and safe procedure under present conditions is to house reindeer at the end of a journey and have available moss for feeding which has been gathered beforehand. It is believed that grain should be added to the moss ration. Well-broken reindeer with good manners, that is to say, reindeer fit for a woman to drive, are uncommon. It is believed, however, that with the more general adoption of improved methods of castration, gentle animals will become more common.

On a few trips made by us with Lapps behind sled reindeer it was noticed that most of the animals used were timid and easily frightened. They would jump off the trail for very little cause. Thereupon both reins would slip over to one side and the animal would stop, facing the driver. To make another start, after the animal had been headed in the right direction, one line was slipped over the back until it was over the root of the tail, when the deer would start off again, perhaps in the right direction. It must be said, however, in all fairness to reindeer, that some of them are gentle and drive well, and this indicates that much more could be done with them than is generally being accomplished at the present time.

The sleds used by the Lapp are not altogether satisfactory. They are so narrow that unless the driver sits with one leg on either side to keep it in an upright position it is very apt to turn over. The Lapp sled has been developed no doubt to travel over rough country where there are no trails, but it is not the best for use in those portions of Alaska where good trails are to be found.

PACKING AND RIDING.

Prospectors occasionally make use of reindeer as pack animals during the summer (Pl. XX, Fig. 3). In cruising about in the hills reindeer are preferable to horses in many respects. They need no

fodder except what they pick up as they go along; they can traverse boggy ground in which a horse would mire; their feet do not have to be shod; and, finally, when they are no longer required for packing they may be slaughtered for food. It is surprising that so little use has been made in Alaska of the reindeer as a pack animal. Doubtless the principal reason is that few animals are broken for this purpose and that little effort has been made to supply the demand.

As regards the weight that a full grown reindeer may support on its back, the reader's attention is called to Plate XX, Figure 2, in which a heavy man is seen astride a reindeer. In Siberia Bertholf saw Tungusic reindeer commonly used as riding animals; he says that some of them are capable of supporting a 200-pound man.

PREDATORY ANIMAL ENEMIES.

The predatory animals that attack reindeer in Alaska are chiefly bears, wolves, lynxes, wolverenes, and eagles. Their depredations are greater in the interior than on the coast, but while important they are not extensive. Bears are the most numerous and destructive enemy. Only a relatively few wolves, lynxes, and wolverenes now remain along the coasts of Bering Sea or the Arctic Ocean; consequently the losses from predatory animals there are comparatively small, but in the interior they become more of a factor. Eagles are largely in the interior and are especially destructive to fawns. It is reported that in Lapland the herders must stay continuously with their reindeer during the night to ward off depredations by wolves, but on the ranges used in Alaska up to this time night herding to keep off predatory animals is rarely necessary.

INJURIES AND DISEASES OF REINDEER.

Reindeer have generally been considered to be very healthy animals, and though our observations substantiate this to a great extent, there are many minor ailments and parasitic diseases which are taking their toll from the herds. No serious epizootic or contagious diseases have been encountered. In Europe it is said that epizootics ravage the herds occasionally, but in Alaska there are no records of any large numbers of reindeer dying suddenly. The deaths which do occur come one or two at a time, and the herds have their ups and downs like cattle or sheep.

In the following paragraphs the diseases will be dealt with under separate heads; treatment and methods of prevention are indicated wherever possible. It will be noticed that some stress has been laid on the slaughter of all animals likely to convey disease to others. Isolation might be equally effective in some cases, but can not be recommended, as there are no facilities at the reindeer camps for such

B20509

FIG. 1.—SLED REINDEER.

Most winter freighting and travel in Alaska is still done with dogs, but reindeer are used to some extent on the Seward Peninsula and northward. Sled reindeer travel on roads from 20 to 35 miles a day. (Photograph by Lomen.)

B20523

FIG. 2.—RIDING REINDEER.

In parts of Siberia reindeer are used for both riding and pack animals. In Alaska, as the above picture shows (from Seward Peninsula), some reindeer are big and strong enough to support a man, but they are nowhere used for riding. (Photograph by Lomen.)

B1926M

FIG. 3.—PACKING REINDEER SOUTH OF THE YUKON.

The prospector has occasionally found reindeer useful as pack animals in summer. At the journey's end the animals may be slaughtered for food. (Photograph by Schneirla.)

B22618

FIG. 1.—FAWN INJURED BY TRAMPLING.

A large piece of skin was torn off the back in the trampling of animals in the corral. The fawn had to be killed.

B22604

FIG. 2.—LONG HOOF.

This disease causes overgrowth of horn with malformation, resulting in a crippled condition of the animal.

purposes. An improvement which large reindeer owners might profitably undertake would be to provide paddocks or stabling for injured and sick animals. The present policy is to raise the standard of the Alaska herds; therefore, no sickly or undersized animals should be kept, and this applies especially to breeding stock.

ACCIDENTS.

Accidents are of common occurrence when herds are being handled in the corrals (Pl. XXI, Fig. 1). A suggestion which reindeer owners could well follow would be to isolate all the injury cases as soon as they occur to prevent further damage to them from trampling by the other animals. If there is no time to attend to injured reindeer while handling of the herd is in progress, they should be left by themselves in some inclosure provided for the purpose until such time as they may be properly looked after. In many cases it will be found advisable to slaughter and dress the most seriously injured animals. In other cases, where treatment seems likely to help, the animal might be treated and then turned out with the herd or fed by hand for a few days. Following this simple suggestion would in many cases be found profitable to reindeer owners. Heretofore, diseased or injured animals have been turned out on the range, without any attention, to live or die, as the case may be.

BROKEN HORNS.

Fawns frequently break their horns when being roped in the corral, especially when they are in the velvet at marking time. These accidents may be eliminated to a great extent by avoidance of overcrowding in the corral and by careful handling. Small wire inclosures are dangerous for fawns when the strands of wire are so far apart that their horns get caught. The older animals also suffer in this regard, and while they may not break their horns, they may be injured otherwise. When a fawn breaks its horn the pedunculated portion of attachment to the skull usually breaks with it. The broken horn must be removed, together with the piece of skull. Care must be taken not to leave a pocket of skin over the exposed part of the brain where pus will find a lodgment. The skin should be trimmed in such a way that it will just cover the opening.

Many fawns die as the result of broken horns. At one round-up 31 fawns suffered the loss of one or both horns. In this case they were killed and dressed, since the owners had found by experience that animals usually die as a result of such injury. In another case, of a total of 550 fawns marked, 73 lost one or both horns. When the horns break without damaging the skull there is an excellent chance for recovery, but if the brain is exposed, unless proper surgical methods are adopted, recovery is doubtful.

BROKEN BONES.

Broken bones are of common occurrence at round-ups, especially at marking time. Rough handling is responsible for most of these breakages. Native herders particularly should be cautioned against injuring the animals that are being marked. A heavy man can easily crush in two or three ribs when he is throwing a fawn on the ground, and legs at times have been heard to snap. Needless to say, severely injured animals should be killed as speedily as possible.

LONG HOOF.

Without entering into a discussion on the probable causes of long hoofs (Pl. XXI, Fig. 2), which are still under investigation, it seems advisable to urge reindeer owners to pay more attention to this overgrowth and to trim and pare the long hoofs so that the deer will be able to walk squarely on their feet. It has been noticed that many cases of lameness in the herds are attributed to this condition; the long hoofs have been left untrimmed, causing the animals to walk on their heels, and ending in the formation of sores. These sores resemble those seen in foot rot. In an affected herd timely attention to the feet would certainly cut down the losses.

FOOT ROT.

All foot troubles are serious when they occur in grazing animals; for as soon as the animal has difficulty in walking it can not feed properly and soon becomes thin and worthless. If the lameness is severe and likely to become worse it is the best policy to destroy the animal. The benefit in this case is twofold; first, if the animal is in good flesh the meat can be used and, secondly, the risk of passing on the disease is eliminated. Foot rot and dermatitis are among the most troublesome of reindeer diseases. The percentage of lame animals in a herd may be considerable. The treatment of advanced cases is hopeless under present conditions where the sores can not be attended to every day.

The most likely method of stopping the spread of the disease would be as follows: On the appearance of the first few cases, segregate or kill the sick animals and collect the healthy ones and drive them through a shallow trough containing a 5 per cent solution of one of the recognized sheep dips. The dipping should be repeated every second or third day. At least one herd owner in Alaska has made preparation to follow out this plan in its entirety. The Lapps have known, probably for centuries, that one way of getting rid of the disease is to drive their herds to a new ground. This is a practical method, as the sick and lame animals were thus left behind and consequently contagion in the herd diminished.

DERMATITIS AND ABSCESSES CAUSED BY WARBLE GRUBS.

During the fly season in July and August, serious cases of dermatitis may often occur (Pl. XXII, Fig. 1). In one herd of about 2,000 animals fully 25 cases were seen. The lesions are most frequently on the hind legs above the hock, but they may also be seen on other parts of the body, such as the stifle, hock, knee, forearm, fetlocks, and shoulder, the frequency being in the order named. Swelling is the first symptom, followed by the death and exfoliation of the skin. The animals feel irritation and bite the affected parts. After the skin has peeled off, large sores are seen, which may attain 6 to 8 inches in diameter. The surface of the wound may be covered with round, raised granulations; in other cases the flesh dies. The sores are evil smelling and are covered with sticky green pus (*Bacillus pyocyaneus*). The fawns and yearlings are the worst sufferers. There are many cases, however, which do not progress as unfavorably as those described above. Many animals have been noticed bearing small lesions and patches of skin denuded of hair. These spots are undoubtedly the result of irritation, and the hair has been nibbled off. According to the Lapps, dermatitis is seen more often during the hot dry summers than in wet seasons, and is most frequent with close-herded animals.

All the evidence obtained pointed to flies as the probable cause of the trouble. Accordingly the skin covering the lesions was carefully examined and numerous eggshells of the warble fly *Oedemagena tarandi* were found. The lesions occur where most of the eggs are deposited, and as it is already known that after the eggs hatch the young larvae bore through the skin, these were also looked for in the sores. Numerous larvae were encountered and it was noted that inflammatory tracts followed them and that they acted as disseminators of the pus, thus enlarging the affected area. It seems clear that the larvae when boring through the skin, drag in the bacteria which happen to be lying upon it. The larvae themselves occasion some swelling and irritation, which favors the development of the bacteria. In view of the fact that cattle suffer similar effects from the penetration of the warble larvae (though in much less severe form), there is no doubt that this evil must be laid at the door of the reindeer warble fly.

The treatment for dermatitis is surgical. All dead tissue must be removed and the wounds dressed with antiseptic solution, either lysol or sulphate of copper being excellent. If the lesions are large or if the joints are involved, the animal must be killed. There is little hope of prevention until means are found for controlling warble flies. But as frequent corralling of animals and close herding during the hot weather expose the reindeer to fly attack, such

practices should be avoided as much as possible. The mortality in some herds may run as high as 1 to 2 per cent.

In one small herd of 700 animals, 9 affected fawns were examined, 5 animals were operated on and released, and 4 were killed on account of the involvement of the hock joints. In another herd of 1,300 reindeer it was learned that 6 fawns had been killed for a similar cause. The strains of *Bacillus pyocyaneus* brought back from Alaska were tested on guinea pigs in the Pathological Division of the Bureau of Animal Industry, where it was found that 0.5 cubic centimeter of a broth culture inoculated intraperitoneally was fatal to guinea pigs in 1 to 4 days.

EYE TROUBLE (KERATITIS).

Inflamed eyes are not of uncommon occurrence. The condition may become aggravated and end in blindness (Pl. XXIII, Fig. 1). It is rare that both eyes are affected, and in only one or two instances were totally blind animals encountered. In one particular case, in a herd of about 3,000 reindeer, approximately 1 per cent of the animals were affected, only one of them being blind in both eyes. The affection seems to be seasonal, starting with the hot weather and disappearing in the autumn. Though the cause of the disease has not yet been ascertained, it would appear to be infectious, and therefore the diseased animals should be slaughtered and not kept as breeding stock. Treatment of the eyes would be valuable if there is any way of doing it regularly. Nitrate of silver solution promises to be the most satisfactory remedy.

WARTS (PAPILLOMA).

Warts seem to be more common in reindeer than in either cattle or sheep, and they often attain large size. While most frequently noticed on the flanks, they may be found on all parts of the body, and are generally black in color, with a narrow neck at the point of attachment. In some of the herds these warts were very noticeable. They appear in the spring and often disappear when the cold weather starts. In the light of recent investigations, it seems possible that they are produced or stimulated by parasites. It does not seem as though much importance need be attached to these growths, but they have attracted the attention of some of the herd owners.

RHEUMATISM.

Rheumatism has been observed in old deer. In life the affected animals show a marked stiffness and a disinclination to move. On post mortem examination roughenings and exostoses of the bones were found, also reddened and turbid synovia in the articulations.

B22709

FIG. 1.—DERMATITIS IN REINDEER FAWN.

This condition follows the penetration of larvae of the warble fly (*Oedemagena tarandi*).

B22654

FIG. 2.—SCREW WORMS (PHORMIA TERRAE-NOVAE) ON REINDEER SKIN.

Infestation is common at the time of year when warble grubs are leaving the backs. When infested with a large number the animal usually dies, hence the necessity for following the methods advocated for prevention.

B1927M

FIG. 1.—EYE DISEASE OF REINDEER.

Blind fawn. This is a summer disease, probably carried by flies, causing permanent blindness, but usually affecting only one eye.

B22605

FIG. 2.—RICKETY 2-YEAR-OLD DOE.

Animals in this condition should be killed and not allowed to breed.

RICKETS.

Rickety conditions are rare in reindeer (Pl. XXIII, Fig. 2). While only occasional cases may be seen, the fact that reindeer crave lime salts at certain times of the year indicates that their systems lack some essential requirement in mineral matter. Toward the end of winter it has been observed that they nibble at each other's horns, and short, stubby, chewed horns may be seen, especially on the fawns. Does may also be found in this condition, their horns having been gnawed off close up to the head. The horns disappear from the range soon after they are shed. Reindeer may injure themselves by trying to swallow too large pieces of bone. In two instances animals were found with pieces wedged tightly beside the molars. Dr. F. H. Gambell, in 1904, on St. Lawrence Island, noted that they showed craving for calcium salts.[14] In some districts it may eventually be found necessary and profitable to feed bone meal.

PARASITES.

Parasites appear to be the worst enemies the reindeer have. They fall into two classes, being both internal and external. The internal parasites will be considered first.

TAPEWORMS.

Tapeworm cysts.—Three forms of tapeworm cysts are found in reindeer, and all three are conveyed by dogs. The dog is the host of the tapeworm and the reindeer is the intermediate host. That no misunderstanding may exist, the three forms will be described separately.

Taenia hydatigena (*T. marginata*) is a common tapeworm in dogs. The mature segments or joints of this worm containing the ripe eggs of microscopic size are passed in the feces of the dog, and are picked up by the reindeer with their grass or other food. The eggs hatch and the young larvae find their way into the body cavity. The liver is generally the organ most affected, and frequently 10 or 12 cysts will be noticed just under the covering. They may also be found in the fatty tissues round about the intestines. The cysts have the appearance of small bladders filled with clear fluid. The bladder worm, as it is called in this state (*Cysticercus tenuicollis*), consists of a head, neck, and bladder. If a dog is fed on raw offal containing these bladder worms he will soon develop tapeworms, and the more raw offal he gets the more tapeworms he is likely to have. The damage caused by these bladder worms in reindeer is confined principally to the liver, which, because of the parasites, is often ren-

[14] See Georgeson, C. C., Reindeer and caribou: Bur. Animal Ind., Circ. 55, U. S. Dept. Agr., pp. 377–390, 1904.

dered objectionable for use as food. Cooking destroys the vitality of the cysts and they are then harmless to dogs.

Taenia echinococcus[15] is a small tapeworm, also a parasite of the dog, and its intermediate form, which is commonly found in reindeer, consists of watery bladders or cysts, generally occurring in the lungs. The cysts are small at first, but gradually enlarge and often attain the size of an orange. Echinococcus cysts persist for years and may kill their host. Reindeer obtain the cysts by swallowing the eggs which are passed by dogs, and dogs obtain the tapeworm by eating raw reindeer meat or viscera containing the cysts. This circle may be broken by treating the dogs with worm medicines and by not feeding them raw meat or offal.

Taenia krabbei also inhabits the intestines of the dog, and its intermediate cystic form, *Cysticercus krabbei*, is unfortunately very common in reindeer. The cysts occur in the muscular tissues and are easily seen, especially in the deep muscles of the quarters. They are small egg-shaped bladders with a white spot showing in the center. Meat in which the cysts are numerous is considered objectionable for use as food.

At least one herd in Alaska seems to be free from the three forms of cysticerci mentioned above. This is on St. Lawrence Island. When reindeer were first introduced on the island, 1902–6, no reindeer dogs accompanied them, and since that time herd dogs have never been used. This fact explains their freedom from cysts. Sled dogs are in use on the island, but they do not come into contact with the reindeer.[16]

Prevention of tapeworms in dogs.—In view of the fact that reindeer obtain three of their worst parasites from dogs, every effort should be made on the part of reindeer owners and others to rid their dogs of tapeworms. Reindeer dogs are undoubtedly the worst offenders. In the first 25 dogs treated for tapeworms it was found that every one harbored the parasites. Sled dogs do not carry so many worms, which is to be expected, as the diet of working dogs consists chiefly of dried salmon and other fish. Of the first 24 malamute sled dogs which were treated only 6 passed worms.

[15] Man as well as reindeer may contract echinococcus cysts by swallowing the eggs of the dog tapeworm, *Taenia echinococcus*.

[16] In an unpublished report made by E. C. Joss, veterinary inspector, Bureau of Animal Industry, 1914, some interesting observations on cysticerci in reindeer are recorded. Joss spent a month in Alaska and made a number of post-mortem examinations of reindeer. He found both *Cysticercus tenuicollis* and *C. krabbei*, and also reported *Taenia echinococcus* in dogs. *C. krabbei* cysts were encountered in the heart muscles in several cases and were also recorded in the cheek and other muscles. Joss treated a number of dogs with tapeworm remedies and obtained many tapeworms, which are now in the collection of the Zoological Division. This note is made through the courtesy of Dr. B. H. Ransom, of the Bureau of Animal Industry, whose advice and assistance have been invaluable in connection with working out the parasites of reindeer.

The form of treatment which was used is based on that recommended by the United States Bureau of Animal Industry and is as follows: The dog should be fasted for 12 hours. It is then given 3 cubic centimeters, or three-fourths teaspoonful of oleoresin male fern in 2 ounces of warm milk. This dose was found satisfactory for sled dogs of ordinary size. The dog's head must be firmly held and the medicine poured slowly into the pouch at the side of the mouth. The medicine will run between the closed teeth, and the dog's jaws need not be separated. As soon as the medicine has been swallowed the dog's head should be tied for a period of three-quarters of an hour so that it can not lower it to vomit, after which a dose of nut areca is administered. This dose consists of 3 grams, or about a level teaspoonful, of freshly ground nut areca diluted with 2 ounces of milk. The dog's head is again kept tied for about half an hour. The dog should be kept chained until it has passed the worms, which must be collected and burned. These directions have been followed by a number of dog owners in Alaska and the reports received have been favorable throughout.

Reindeer tapeworms.—Two species of tapeworm have been found in reindeer. One, a species of Moniezia, has been collected in six different herds. The other worm is evidently rarer and has only been found once. The tapeworms often attain a length of 10 feet or over and as many as nine have been taken from a single fawn. When the worms are numerous the fawns must necessarily be adversely affected. Unfortunately, no satisfactory method of prevention has been developed so far, since the life history of the worm is unknown. However, it has been noticed that the worms are more numerous in closely herded animals, which is an indication that the old grazing grounds are the most heavily infested. These tapeworms seem to attack young animals almost exclusively, and in only one instance were they encountered in an adult.

LUNG WORMS (DICTYOCAULUS Sp.).

Lung worms, as their name implies, are to be found in the lungs. In bad cases the air tubes may be filled with tangled skeins of worms. Paroxysms of coughing occur and the deer often project masses of mucus several feet in front of them. Usually, however, the coughed-up mucus is swallowed, and the worm eggs which are contained in it are passed through the alimentary canal with the droppings. Broncho-pneumonia is associated with lung worms. The adult worms are found in the 2-year-old reindeer and also in some cases in old animals, where they were collected in great numbers. The eggs of lung worms hatch as a rule in the lungs, or if they are coughed up, they hatch outside the body on the ground and are thus passed on to other animals, which pick them up while grazing.

ROUNDWORMS IN THE STOMACH AND INTESTINES (OSTERTAGIA AND NEMATODIRUS).

It is believed that roundworms are responsible in a large measure for unthriftiness in young reindeer. Anemic fawns have been examined where no other parasites or disease could be held responsible for their lack of condition. The worms are small, the *Ostertagia* in the stomach being as fine as hair, but sometimes occurring in such numbers as to give the lining of the fourth stomach a reddish appearance. The *Nematodirus* worms in the intestine are larger and belong to two different undescribed species. They have been found in a number of cases in young reindeer, sometimes occurring in large numbers. These intestinal roundworms have a direct life history; the eggs are passed out with the feces and hatch upon the ground, and the larvae are then picked up by reindeer. Close and frequent grazing over the same ground will predispose animals to becoming heavily infested by these parasites.

PREVENTION AND TREATMENT OF WORMS.

No attempts at the drug treatment of reindeer for worms have as yet been made. Prevention, however, has been essayed in a small way on reindeer allotments. If reindeer owners follow the recommendations made in the fore part of this bulletin about rotation and open grazing, they will materially cut down the losses from worms. The following examples serve to show how proper range management may prevent losses and improve the condition of a herd:

During the winter of 1920–21 definite proof through post mortems was obtained that a small herd of about 1,400 reindeer was heavily infested with a variety of parasites. The native owner reported that during the previous summer he had lost 100 fawns from sickness. The parasites which were found in his animals included three kinds of tapeworms, cysts derived from dogs, and several species of roundworms. The owner was advised to treat his herd dogs for the removal of tapeworms. He was also told that his animals must have been grazing for too long a period over the same area. This he admitted to be the case, and stated that when he first came to his allotment his deer were much admired for their size and condition. He had remained on the allotment for the past eight years, but during the last four seasons he had noticed that his animals were losing in condition year by year and his losses had reached a point where they were causing him grave concern. He was advised to find new grazing ground during the following summer and to keep his animals moving, so that they would not remain over two weeks on a given area. The herd was reinspected during the latter part of September, 1921, and it was gratifying to note that the animals had

improved very greatly in size and condition. The owner stated that his losses in fawns during the summer had been only six animals.

Further support can be brought to show that this improvement was not mere accident. Some 200 animals belonging to this herd were removed early in the season to another allotment. These were also nspected during September, and four fawns and two adults were killed on account of skin troubles (dermatitis). The fawns were found quite free from evidence of tapeworm infection, that is, those forms which are derived from dogs, and no other worms were found n the animals. It is, of course, possible that a few minute worms nay have been overlooked, but the fact remains that the fawns were lean and healthy in every particular, except for the aforementioned kin troubles. At the same time, the two older reindeer which were laughtered still harbored a considerable number of parasites. The bvious lesson to be derived from this experience is that once reindeer re infected with parasites, they are apt to retain some species for ong periods and to be capable of passing them on to other animals, specially the young, providing they are kept in close contact, or, n other words, close herded for too long periods on the same piece of round.

In the example just cited we have a herd full of parasites. The nimals are put on new ground and are kept constantly moving at wo-week intervals during the warm months, when parasites are nost readily transferred. The fawns grow up strong and healthy ithout parasites, though their mothers are infected. The reason or this healthy condition and freedom from parasites is that the orms which leave the mother reindeer in her feces take some days hatch upon the ground and to reach a stage where they are ready infect new hosts. It is hoped that future investigations will yield efinite facts as to the exact time required for the various parasites hatch on the ground and become infective for other animals. At ne present time, and until proper open herding methods are used, is recommended that during the warm season, particularly from une to the end of September, the herds be moved at least every vo weeks to fresh ground and that the animals be not brought back graze on areas which have been considerably used earlier in the ason. Worm larvae are very resistant and will remain on the round for long periods waiting to attack their hosts.

WARBLE FLIES (OEDEMAGENA TARANDI).

The warble fly of reindeer is a beelike insect of yellowish orange loration. The life history will be given only briefly in this bulle- n, as it is proposed to publish later a more detailed account of the sect. The fly is on the wing in the latter part of June and has

been captured as late as September 9, so that its season of activity covers three months in favorable years. Being an arctic species, it can withstand much more cold and wet than southern species of warble flies. The eggs are laid mainly on the fine, woolly hairs which constitute the under down of a reindeer coat, principally on the parts which come in contact with the soil when the animal lies down; this means the flanks, brisket, and the upper part of the legs.

The fly lays its eggs both when reindeer are standing and lying down. When it lays on standing animals it causes them much uneasiness, and during hot weather it is common to see a herd "milling" or moving round and round in circles. Some of the animals will be seen running, others kicking and stamping; meanwhile the fawns will be uttering their grunting plaints of *oh-oh-oh*. The whole scene gives the impression of worry and unrest and makes one feel as the great Linnaeus did when he first saw these flies at work in Lapland, that even a small insect can bring much trouble into the world. Fortunately, the warble fly does not always keep the animals so restless. When the herd is resting the flies adopt gentler tactics, and they may be seen on the ground busily depositing their eggs on the reindeer hair without causing any annoyance other than, perhaps, a slight tickling at times. In this case the insect backs up, gently pushes its long ovipositor into the hair, and lays its eggs without necessarily alighting on the deer.

Experimentally, the eggs have been found to hatch in 6 to 7 days, and the young larvae to bore through the skin. Though this act of boring has not been witnessed in reindeer, there is no doubt that the grubs do go through the skin. They have been found in large numbers just under the skin, and as many as 107 were counted on one hind and one front leg of one animal. These young grubs are very minute, and numerous examples about 1 millimeter in length were found. The grubs may be found on the legs and body quite early in the season, and in 1921 they were seen as early as August 4.

There is a definite migration of the larvae from the point of entrance toward the back.[17] The first grubs to reach the back and bore through to the outside were found on September 26. These were two in number. A week or two later hides may be found with numerous punctures. It is not until toward the end of October that the holes through the skin attain any size. However, even the smallest hole causes an irreparable injury when a skin is tanned.

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[17] In an unpublished report of 1914, Joss recorded the finding of two small warble larvae along the gullet. This is of interest in that in the present investigation larvae were not encountered in this position. In Bergman's investigations in Sweden there are no records of the larvae being found inside the body cavities. It is possible that the larvae which Joss found may have been erring or lost. In the present investigation in Alaska, larvae were encountered deep in the muscles, having evidently taken a wrong course in their migration to the back.

The larvae grow progressively and evenly in size until May, and ıe earliest grubs emerged (1921) on May 12. It is quite likely that very few may come out prior to this date, and not many are left ehind in the skin on July 1. The time of greatest emergence of rubs is during June.

The larvae pupate, or harden, in a day or two, depending pon the state of moisture surrounding them. There are no satis-ıctory records for Alaska as to the average period required for ıe emergence of the fly. In trials which were made in 1921, the upae were kept too moist, owing to unavoidable circumstances, so ıat though a few of the flies emerged, they did so after a length-ıed interval. Bergman states that in Sweden the pupal stage aver-ges about 27 days.[18] No doubt in Alaska it will be found that the eriod is of similar length.

The damage done by warble flies is difficult to estimate. In laska, though reindeer are sometimes burdened with several hun-red larvae in their backs, and in rare cases may have as many as thousand (Pl. XXIV), it seems that there is considerable toler-ıce of the parasites by the animals. In other words, the reindeer ıpport a large number of warble larvae without showing much ıffering or loss of condition. That there is a defensive reaction on e part of the reindeer against the grubs is shown by the fact that ıe yearlings have the most larvae, but when they reach 3 years of ;e it often happens that they have only a few grubs, and when ıult life is reached at 5 or 6 years they may escape altogether. he reaction on the part of reindeer to warble larvae is mani-sted by the formation of pus and by the production of a sac which closes the grub after it has taken up its permanent place of abode ı the back. The amount of pus secreted is not so great as is that creted by cattle against *Hypoderma*, the cattle warble-fly.

Reindeer skin is very thin and the larvae make a large opening the time they are ready to leave the body. These openings, to-ther with the presence of pus, expose the yearling reindeer, ɔecially, to the attacks of screw worms. It has been found that is a very simple matter to extract the larvae by squeezing the skin. ıis causes the reindeer little pain and the operation is quickly ne. If the yearlings were thus treated in April and May, danger ɔm screw worms would be eliminated almost entirely, as the cavi-s in the backs would have healed before the blow flies appear, ıich is at a later date.

The suggestion has been made that does be separated from the rest the herd at fawning time. When this is done, the bucks and

[18] Bergman, Arvid, On the Oestridae of reindeer: Entomologisk Tidskrift, vol. 38, pp. 12, 113–146, 1917.

yearlings can be driven into the corral, and the young animals treated during the fawning season. Extraction of the grubs is apparently a safe procedure. Experiments were made to determine whether injection of the juices contained in the larvae would seriously affect the reindeer. While some slight results were obtained, it was proved in a few cases that reindeer can withstand large doses of the warble fluids. In the latter part of April and early in May the warble grubs are large, and their skin is very tough, so that it is unlikely that they would be ruptured during the process of removal. Besides, as a reindeer skin is soft and pliable, the squeezing out of the grubs presents no difficulty. Theoretically, if all warble larvae were thus squeezed out and destroyed, there should be no flies left to attack the animals. Unfortunately, warble flies are able to travel long distances, and seem to have the power of following animals and of catching up with a herd.

It was suggested to one reindeer owner some years ago that he try the following method: After most of the grubs have left the reindeer, about July 1, drive the animals as far away as possible from the point where the grubs have fallen, the idea being that when the flies emerged from the pupal cases they would not find any reindeer to attack, and as they only live for a few days they would soon die. The owner, A. H. Twitchell, reported a measure of success from following this method; and, when his herd was visited, it was remarked that the hides seemed to be less affected with warbles than those seen in other herds. It is thought that the distance which reindeer must be driven should be not less than 15 miles, but the point has not been definitely settled.

In connection with the elimination of warble flies it is interesting to note that the St. Lawrence Island herd has been free from warbles ever since it was established. The reindeer were derived from the same sources as the other Alaskan herds. It would appear that they may have been transported to the island after all the grubs had left their backs and before egg-laying had started. St. Lawrence Island was visited during the summer of 1921 and the matter was investigated. No sign of either *Oedemagena tarandi* or *Cephenomyia nasalis*, the nostril fly, was seen.

Lapp names for *O. tarandi* are as follows: The larva is called gourma or gourbma; and the imago or fly, batta-bosska.

NOSTRIL FLIES (CEPHENOMYIA NASALIS) (C. TROMPE).

The nostril fly of reindeer is a blackish beelike insect with a round abdomen. Its habits are quite unlike the warble fly, and it causes far more annoyance to reindeer than the latter. It has about the same seasonal activity as the warble fly, or from June to September, bu

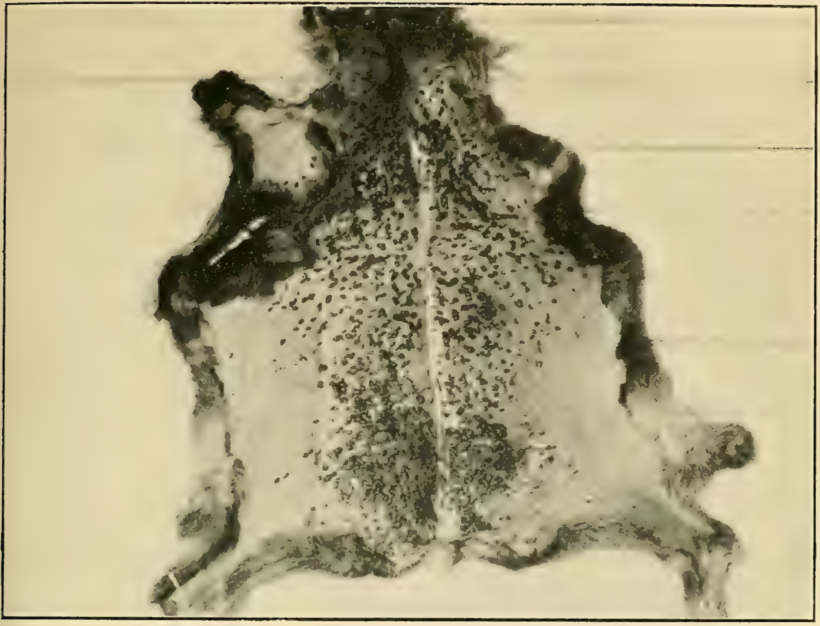

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FIG. 1.—YEARLING SKIN INFESTED WITH WARBLE GRUBS.

About 1,000 larvae of the warble fly (*Oedemagena tarandi*) were counted on the back. With such a number the hide was practically riddled, one hole being punctured by each grub. More parasites were counted on the right side than on the left.

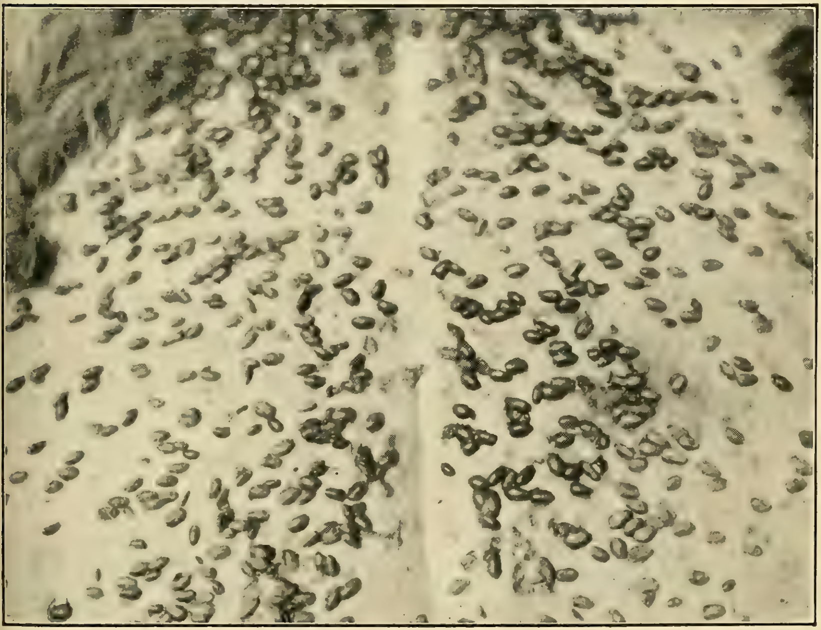

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FIG. 2.—NEAR VIEW OF ABOVE SKIN.

In a line along the backbone the skin is free from grubs, explained, no doubt, by the pressure and movements of the bone.

is never so numerous. Instead of laying eggs, it deposits live larvae in the nostrils of reindeer.

The method of attack is peculiar. The fly hovers for a few moments in front of the nostrils, then darts in and deposits a drop of wriggling larvae at the entrance to the nose. The larvae work their way up the nostrils and attach themselves at the back just in front of the entrance to the throat.

The effect on reindeer of this method of larval deposition is most marked. The animals are terrified by the insect's attack, and when it is hovering in front of their noses they assume a terror-stricken look, their eyes staring, their mouths open, and their bodies in a tensely strained attitude. When a reindeer is in this rigid state, the slightest touch on any part of the animal will cause muscular contractions which shake the whole body, just like an electric shock. When the insect deposits its larvae, such a shock follows. It is succeeded by a total relaxation, the deer evidently realizing that it is not likely to be struck twice by the same insect. The animal appears nauseated and walks a few steps with its head elevated, sneezing and showing signs of nasal irritation.

Once the larvae are firmly attached in their habitat at the back of the nostrils, they seem to cause the reindeer very little annoyance. Their growth is slow and they do not greatly increase in size until about the end of March, at which time they appear to grow most rapidly, attaining their full size in the early part of May. The first larva seen to emerge appeared on May 12. The last date of emergence has not been ascertained definitely, but presumably it is about the same as for the warble fly.

When the larvae are mature they cause the reindeer much suffering and annoyance. Two young animals which were kept at the Unalakleet station were watched carefully, and it was observed that the larvae kept them in a constant state of worry, even when they were at rest. They would elevate their heads and sniff in an evident attempt to dislodge the parasites. At other times they coughed and sneezed. But though these attempts to dislodge the parasites were almost continuous, the reindeer seldom appeared to use really vigorous efforts, apparently owing to fear. The expulsion of the larvae was observed on several occasions, and almost invariably when a larva fell to the ground it was red in color, being coated with a thin film of blood.

It is surprising to note that nasal discharges in reindeer are slight in comparison with those of sheep when the latter are harboring *Oestrus ovis*, which is very similar to the reindeer fly in habits. Reindeer, however, show symptoms of staggers, or "false gid," such

as are seen in sheep, a form of dizziness induced no doubt by the irri tation caused by the larvae. Bergman mentions a disease callec "varka" in Lapland which he attributes to *Cephenomyia nasali* and which he says may cause death.[19] In Alaska there are no rec ords of reindeer dying from grubs in the nose, but it is quite possibl that occasional deaths do occur.

After the larva has fallen to the ground it pupates rapidly, in five o six hours as a rule. It differs in this respect from *Oedemagen tarandi*, which is much slower. The pupal period is shorter than i is for *O. tarandi.* According to Bergman, the pupal stage may b from 16 to 31 days. In observations made in Alaska, the pupa period lasted up to 56 days, but this was under adverse conditions and only 20 flies emerged out of a total of 54 pupae.

The treatment or prevention of nostril flies seems even mor hopeless than is the case with warble flies. The only means of pre vention that seems at all likely to succeed would be to provide dark ened shelters for the reindeer to go into when the flies are attackin them. In northern Europe, especially on the Finnish side in Lap land, long dark sheds are provided, and the Lapps say that withou such protection reindeer would suffer greatly in some districts Shelters would be most helpful against the warble fly as well an would also afford the reindeer some protection from other forms o insect life. Unfortunately, in arctic latitudes the insects are a work the greater part of the 24 hours; consequently, during the ho weather the reindeer might not get very much chance for feeding But on the other hand, if the animals have no means for protectin themselves they suffer so much annoyance and worry that the los of a little food would seem preferable.

Lapp names for *Cephenomyia nasalis* are as follows: The larv is called saula; and the imago or fly, boaro.

SCREW WORMS (PHORMIA TERRAE-NOVAE).

Blowflies are found in abundance on all the reindeer allotments Both natives and whites are careless in the disposition of refuse; con sequently, on approaching a reindeer herder's cabin, swarms of blow flies may be seen rising from rubbish heaps containing reindeer offal fish refuse, and other offensive material. Reindeer that die on th range are usually left where they lie. It is no wonder, therefore that wounds may become infected with screw worms. A heavil infected skin taken from a reindeer on May 20 is illustrated i Plate XXII, Figure 2.

The most important factor predisposing reindeer to infestatio with screw worms in the warble fly. When the warble larvae emerg

[19] Bergman, Arvid, On the Oestridae of reindeer: Entomologisk Tidskrift, vol. 38, pp 1–32, 113–146, 1917.

from the reindeer in spring large openings (in some cases, hundreds) filled with pus may be seen in their backs. Blowflies are attracted to these and it is reported that in some seasons considerable losses may follow blowfly attack. Prevention of this form of loss has been discussed under Warble Flies, p. 61.

Screw worms have been found infesting wounds resulting from other causes, such as broken horns and sores on the legs. In these cases the removal of the grubs and the surgical treatment of wounds will bring about a cure. Proper disposal of refuse and carcasses should bring about a diminution of blowflies. Burning is the most satisfactory method, and next to this comes burial; in Alaska, however, owing to the frozen state of the ground, burial is not always possible, and fuel for burning is sometimes scarce. When burial is possible, at least 2 feet of soil should cover the carcass. Lime and oil are of assistance in the destruction of larvae and may be used to advantage. A carcass soaked in oil can be set fire to and many grubs thus destroyed. Cleanliness around native villages could easily be enforced, and the reprehensible practice of throwing carcasses of dead dogs on the seashore should be stopped. It is true that many dogs have to be killed each spring, but the work should be done under supervision and the animals should be burned or properly buried.

MOSQUITOES.

Mosquitoes are a serious pest in the north and cause much annoyance to man and beast. In Alaska they consist of only a few species, although they are very numerous. Reindeer suffer a great deal from the mosquito, but being so heavily coated they appear to resist attack better than do some animals, excepting during the time when their hair is newly shed.

Culiseta alaskaensis Ludlow [20] and *C. impatiens* Walker are the large snow mosquitoes which come out early in spring. *Aedes punctodes* Dyar is the common form, and is the worst mosquito attacking reindeer on the coast of Alaska, where it appears about the latter part of June. The Lapps always say that the mosquitoes help them to round up their herds at marking time, about June 20; it is probable, however, that the warble fly, which appears about that time, may also play a part. According to Dyar, *Aedes cataphylla* Dyar, of which a few specimens were collected on the coast, is the species which is abundant along the Yukon Valley.

LICE.

The only surface-skin parasites of reindeer found up to the present time are lice, and these have been encountered in only small numbers.

[20] Determinations of the mosquitoes collected in Alaska were made by Dr. H. G. Dyar, of the Bureau of Entomology.

While lice in cattle are more numerous in certain seasons, it was not observed that the reindeer were bothered to any extent in Alaska. Reindeer men report that they have at times noticed a loss of hair in reindeer which may have been due to attacks of lice.

PROTOZOA.

The Protozoa found in reindeer require further study. *Sarcosporidia* in the muscles are of common occurrence. In cattle and sheep these parasites are usually regarded as having little significance, but in reindeer there are some cases at least where the numbers of the cysts are so great that value of the meat is lowered. A disease called by reindeer men "cornmeal," which is also caused by Protozoa,[21] is noticed when affected animals are skinned; there is found to be a decided roughening of the bones and tendons, hence the name "cornmeal." It would be difficult to detect these cases in the live animals. Young reindeer do not seem to be infested, or only to a slight extent. The old animals are the most heavily parasitized.

PATHOLOGICAL CONDITIONS IN GENERAL.

In the survey of the reindeer industry in Alaska, no serious outbreaks of contagious diseases were encountered. It would seem that reindeer are more fortunate than either cattle or sheep in this regard.

Parasites are undoubtedly the worst enemies reindeer have, and fortunately the outlook for controlling some species seems hopeful. For instance, the worms which reindeer derive from dogs can be reduced simply by treating the dogs with vermifuges. The remedy lies in the hands of the reindeer owners.

Bacterial diseases, such as foot rot, have been mentioned in the preceding paragraphs: there are, however, several other bacterial diseases requiring further investigation, such as lung affections and diseases of the heart.

Septic conditions of lungs and the coverings of the heart are not uncommon. It may be found that these cases are brought on mechanically by the penetration of foreign bodies from the paunch. In those cases which were examined for bacteria, a variety of organisms were encountered.

In concluding this chapter on disease, it will be well to caution all reindeer men against keeping sickly animals in their herds. *If there is any doubt about an animal, it should be killed without hesitation. Great losses may often be averted by prompt action of this nature.*

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[21] Cf. Hadwen, Seymour, Cyst-forming Protozoa in reindeer and caribou: Journ. Amer. Vet. Med. Assn., vol. 61, n. s. vol. 14, no. 4, pp. 374–382, figs. 1–8, July, 1922. In this article the parasite of "cornmeal" disease is described, and named *Fibrocystis tarandi.*

SUMMARY.

Alaskan reindeer are derived from the original importations of 1,280 animals from Siberia by the Bureau of Education during 11 years beginning in 1892. In 30 years the herds have increased to from 130,000 to 200,000, and probably 100,000 additional have been killed for meat and skins. It is estimated that grazing areas in Alaska will support from 3,000,000 to 4,000,000 head. The herds are owned chiefly by natives, for whose use they were originally imported, but white men have gradually acquired stock, and under their management the conditions of both their own herds and those of the natives should improve.

From a preliminary survey of grazing, range, and herd management and of diseases and parasites, made possible under an appropriation which became available on July 1, 1920, it is evident that the development of the reindeer industry requires white supervision, with proper markets, improved transportation and cold storage facilities, grazing on the system of allotted ranges, improvement of herd management, enactment and enforcement of a brand registry law, and the control of diseases and parasites.

Efficient range management involves attention to the carrying capacity of the range, with an avoidance of both overgrazing and undergrazing, the former being detrimental to the reindeer and the latter being wasteful.

Company herds are advocated, in which ownership of does shall be the basis of dividends and of cost assessments.

Distribution of the herds over the range may be improved by salting. Line fencing between range allotments may in some cases be advisable, but this will not take the place of efficient herding.

The experiment of crossing reindeer does with caribou bulls is contemplated for grading up the stock and increasing weights. Old and scrubby does as well as the same quality of bucks must be eliminated and better bucks must head the herds to increase the average size of the fawns. White reindeer are deficient in vitality and size, and while an aid in locating a herd, are undesirable and should not be permitted to breed.

Rough handling of herds in round-ups and corrals must be eliminated to lessen accidents and fatalities.

Notching ears as a means of identification is unsatisfactory and if possible should be superseded or accompanied by branding.

Dehorning reindeer was tried without success. Castration of bucks after the velvet has been shed causes the horns to drop. Modern methods of castration should take the place of those heretofore practiced by the Lapp and Eskimo herders.

Rutting starts August 25 and ends in October. Reindeer should be held in good grazing areas during this period and in the fawning season. Experiments demonstrate that reindeer may be fed like cattle, but this would probably not be an economic success.

While no serious contagious diseases of reindeer have occurred in Alaska, control of certain diseases and of parasites must be undertaken. Killing diseased reindeer promptly is recommended to prevent spread of contagion in the herds.

The warble fly (*Oedemagena tarandi*) is a serious reindeer parasite, damaging the hides and causing abscesses on the legs. Tapeworm cysts, for which dogs are responsible, will disappear in reindeer by proper treatment of dogs.

Reindeer meat is at its best in autumn, and the right time for slaughtering is in October and November. Earlier than this the back fat is not fully laid on, and later the parasitic larvae depreciate the value of the meat.

The reindeer industry in Alaska promises to become a large factor in the development of the Territory and should be encouraged in every practicable manner.

CHECK LIST OF ALASKAN RANGE PLANTS.

The following list includes the plants that have been identified as occurring on the reindeer range of the coast lying between Point Hope and Kuskokwim Bay, including Nunivak and St. Lawrence Islands. This list is compiled largely from collections made during the investigations and in part from the collection of Charles Thornton, of Nome, Alaska, a local botanist.

GRASSES.

Agropyron sericeum (wheatgrass).
Agrostis aequivalvis (redtop).
Agrostis borealis (redtop).
Alopecurus alpinus (foxtail).
Arctagrostis latifolia.
Calamagrostis scabra (coast bluejoint).
Elymus arenarius (dunegrass).
Elymus mollis (dunegrass).
Festuca rubra (red fescue).
Festuca rubra barbata (fescue).
Festuca rubra subvillosa (fescue).
Phleum alpinum (wild timothy).
Poa arctica (bluegrass).
Poa eminens (giant bluegrass).
Poa hispidula (bluegrass).
Trisetum spicatum.

GRASSLIKE PLANTS.

Carex aquatilis (sedge).
Carex atrofusca (sedge).
Carex canescens (sedge).
Carex compacta (sedge).
Carex concolor (sedge).
Carex helconastes (sedge).
Carex lachenalli (sedge).
Carex macrochaeta (sedge).
Carex membranacea (sedge).
Carex rotundata (sedge).
Carex scirpoides (sedge).
Equisetum arvense (horsetail).
Equisetum palustre (horsetail).
Equisetum sylvaticum (horsetail).
Eriophorum angustifolium (large cotton sedge).

Eriophorum callitrix (small cotton sedge).
Eriophorum vaginatum (cotton sedge).
Juncoides arcuatum (wood rush).
Juncoides campestre (wood rush).
Juncoides kjellmannianum (wood rush).
Juncus castaneus (rush).
Juncus haenkei (rush).
Sparganium hyperboreum (bur-reed).
Torresia alpina (sedge).
Zostera marina (eelgrass).

WEEDS (HERBACEOUS PLANTS).

Achillea borealis (yarrow).
Aconitum delphinifolium (monkshood).
Allium sibiricum (onion).
Alsine (stellaria).
Amsinckia menziesii (fiddleneck).
Androsace chamaejasne.
Anemone multiceps (anemone).
Anemone narcissiflora (anemone).
Anemone parviflora (anemone).
Anemone richardsoni (anemone).
Antennaria borealis (everlasting).
Antennaria monocephala (everlasting).
Arenaria arctica (sandwort).
Arenaria macrocarpa (sandwort).
Arenaria verna (sandwort).
Arnica alpina (arnica).
Arnica nutans (arnica).
Arnica obtusifolia (arnica).
Arnica unalaschensis (arnica).
Artemisia arctica (wormwood).
Artemisia semavinensis (wormwood).
Artemisia tilesii (wormwood).
Aster sibiricus (aster).
Astragalus alpinus (loco).
Astragalus littoralis (loco).
Barbarea barbarea (wintercress).
Barbarea orthocerus (wintercress).
Bupleurum americanum (hare's-ear).
Caltha nutans (marsh marigold).
Caltha palustris arctica (marsh marigold).
Campanula lasiocarpa (bellflower).
Campanula rotundifolia (bellflower).
Campanula uniflora (bellflower).
Campe (barbarea).
Capnoides pauciflorum.
Capsella bursa-pastoris (shepherd's-purse).
Cardamine bellidifolia (bittercress).
Cardamine blaisdellii (bittercress).
Cardamine pratensis (bittercress).
Cardamine purpurea (bittercress).
Cardamine unbellata (bittercress).
Castilleja tristis (paintbrush).
Cerastium alpinum (chickweed).
Cerastium arcticum (chickweed).
Cerastium minimum (chickweed).
Cheirinia cheiranthoides (wallflower).
Chrysanthemum arcticum (daisy).
Chrysanthemum integrifolium (daisy).
Chrysosplenium beringianum (golden saxifrage).
Chrysosplenium tetandrum (golden saxifrage).
Cicuta douglasii (water hemlock).
Claytonia eschscholtzii (spring beauty).
Claytonia sarmentosa (spring beauty).
Claytonia tuberosa (spring beauty).
Cochlearia fenestrata (spooncress).
Cochlearia oblongifolia (spooncress).
Coelopleurum gmelini (parsnip).
Conioselinum gmelini (hemlock parsley).
Delphinium blaisdellii (larkspur).
Delphinium brownii (larkspur).
Dianthus repens (pink).
Dodecatheon frigidum (shooting star).
Draba alpina (whitlow).
Draba borealis (whitlow).
Dryas octopetala (dryad).
Epilobium anagallidifolium (willow-weed).
Epilobium angustifolium (common fireweed).
Epilobium bongardi (willow-weed).
Epilobium latifolium (broadleaf willow-weed).
Erigeron hyperboreus (daisy).
Erigeron uniflorus (daisy).
Eritrichum arctioides (Arctic forget-me-not).
Galium boreale (bedstraw).

Gentiana frigida (gentian).
Gentiana glauca (gentian).
Gentiana propinqua (gentian).
Gentiana prostrata (gentian).
Gentiana tenella (gentian).
Habenaria bracteata (orchid).
Habenaria hyperborea (orchid).
Habenaria obtusata (orchid).
Hedysarum americanum (jointpod).
Hedysarum mackenzii (jointpod).
Heracleum lanatum (cow parsnip).
Heterotrichum monticola (purple aster).
Heterotrichum subsinuatum (purple aster).
Hippurus vulgaris (marestail).
Iris setosa (Arctic iris).
Lagotis minor.
Lathyrus maritimus (beach pea).
Leontodon lyratum (dandelion).
Leontodon taraxacum (dandelion).
Lesquerella arctica (bladderpod).
Ligusticum macouni (Macoun lovage).
Ligusticum scothicum (Scotch lovage).
Linnaea borealis (twinflower).
Lloydia serotina.
Lomatogonium rotatum.
Lupinus (lupine).
Lychnis apetala (campion).
Matricaria criscoidea (camomile).
Matricaria hookeri (camomile).
Menyanthes trifoliata (buckbean).
Merckia physodes (water starwort).
Mertensia eastwoodae (bluebells).
Mertensia paniculata (timber bluebells).
Moehringia lateriflora (trailing sandwort).
Montia rivularis (spring beauty).
Myosotis alpestris (forget-me-not).
Nasturtium palustre (marshcress).
Oxyria digyna (mountain sorrel).
Oxytropis campestris (oxytrope).
Oxytropis mertensiana (oxytrope).
Oxytropis nigrescens (oxytrope).
Oxytropis podocarpa (oxytrope).
Oxytropis sewardensis (oxytrope).
Papaver nudicaule (Iceland poppy).
Papaver nudicaule multiceps (Iceland poppy).
Parnassia kotzebuei.
Parnassia palustris.
Parrya nudicaulis (Parry mustard).
Pedicularis arctica (fernweed).
Pedicularis capitata (fernweed).
Pedicularis labradorica (fernweed).
Pedicularis langsdorfii (fernweed).
Pedicularis perviflora (fernweed).
Pedicularis sudetica (fernweed).
Pedicularis versicolor (fernweed).
Pedicularis verticillata (fernweed).
Pentstemon procerus.
Petasites frigida (butterbur).
Phlox sibirica (phlox).
Pinguicula vulgaris (butterwort).
Pneumaria maritima (beach bluebells).
Polemonium acutiflorum.
Polemonium humile.
Polygonum alaskanum (smartweed).
Polygonum aviculare (knotweed).
Polygonum bistorta (smartweed).
Polygonum plumosum (smartweed).
Polygonum viviparum (smartweed).
Potentilla biflora.
Potentilla egedii (fivefinger).
Potentilla elegans (showy fivefinger).
Potentilla emarginata (fivefinger).
Potentilla fruticosa (shrubby cinquefoil).
Potentilla nivea (small woolly cinquefoil).
Potentilla palustris (marsh fivefinger).
Potentilla uniflora (fivefinger).
Primula borealis (primrose).
Primula egaliksensis (primrose).
Primula eximia (primrose).
Primula sibirica (primrose).
Pyrola grandiflora.
Radicula palustris (yellow cress).
Ranunculus chamissonis (buttercup).
Ranunculus hyperboreus (buttercup).
Ranunculus nivalis (buttercup).
Ranunculus pallasii (water buttercup).
Ranunculus pygmaeus (buttercup).
Ranunculus sceleratus (buttercup).
Ranunculus sulphureus (buttercup).
Ranunculus verticillatus (buttercup).
Rhinanthus crista-galli (yellow rattle).
Rumex acetosa (sour dock).
Rumex occidentalis (dock).
Rumex occidentalis nanus (dock).
Sagina saginoides (pearlwort).
Sanguisorba microcephala (burnet).
Sanguisorba sitchensis (Alaska burnet).
Saussurea monticola (sawwort).
Saxifraga bracteata (saxifrage).

Saxifraga bronchialis (saxifrage).
Saxifraga cernua (saxifrage).
Saxifraga eschscholtzii (saxifrage).
Saxifraga flagellaris (saxifrage).
Saxifraga foliolosa (saxifrage).
Saxifraga hieracifolia (saxifrage).
Saxifraga hirculus (saxifrage).
Saxifraga neglecta (saxifrage).
Saxifraga nelsoniana (saxifrage).
Saxifraga oppositifolia (saxifrage).
Saxifraga radiata (saxifrage).
Saxifraga rivularis (saxifrage).
Saxifraga serpyllifolia (saxifrage).
Saxifraga unalaschensis (saxifrage).
Sedum integrifolium (stonecrop).
Senecio atropurpureus (senecio).
Senecio frigidus (senecio).
Senecio lugens (senecio).
Senecio palustris (senecio).
Senecio pseudo-arnica (senecio).
Senecio resedifolius (senecio).
Senecio thorntoni (senecio).
Senecio walpolei (senecio).
Sieversia glacialis.
Sieversia rossii.
Silene acaulis (moss campion).
Smelowskia calycina.
Solidago multiradiata (goldenrod).
Sophia sophloides (tansy mustard).
Statice arctica (thrift).
Stellaria longipes (starwort).
Stellaria media (starwort).
Thalictrum alpinum (meadow rue).
Tofieldia coccinea (false asphodel).
Tofieldia palustris (false asphodel).
Trientalis europaea arctica (star-flower).
Valeriana capitata (valerian).
Veratrum spicatum (false hellebore).
Veronica stelleri (speedwell).
Vicia (vetch).
Viola biflora (violet).
Viola palustris (violet).
Zygadenus elegans (death camas).

BROWSE (WOODY PLANTS).

Alnus alnobetula (alder).
Andromeda polifolia (bog rosemary).
Arctous alpina (alpine bear-berry).
Betula kenaica (birch).
Betula rotundifolia (ground birch).
Cassiope tetragona (moss heather).
Cornus suecica (herb dogwood).
Diapensia lapponica (diapensia).
Empetrum nigrum (crowberry).
Ledum decumbens (Alaska tea).
Ledum groenlandicum (Alaska tea).
Ledum palustre (Alaska tea).
Rhododendron lapponicum (rhododendron).
Ribes triste (red currant).
Rosa acicularis (rose).
Rubus arcticus (Arctic raspberry).
Rubus chamaemorus (salmonberry).
Salix arctica (Arctic willow).
Salix fuscescens (bog willow).
Salix glauca (grayleaf willow).
Salix phlebophylla (skeleton willow).
Salix pulchra (diamondleaf willow).
Salix reticulata (netleaf willow).
Salix richardsonii (Richardson willow).
Salix rotundifolia (roundleaf willow).
Spiraea steveni (spiraea).
Vaccinium oxycoccus (small cranberry).
Vaccinium uliginosum (blueberry).
Vaccinium vitis-idaea (mountain cranberry).
Viburnum pauciflorum (highbush cranberry).

FERNS AND FERN ALLIES.

Dryopteris dilatata (shield fern).
Dryopteris fragrans (shield fern).
Filix fragilis (brittle fern).
Filix montana (brittle fern).
Lycopodium alpinum (clubmoss).
Lycopodium annotinum (clubmoss).
Lycopodium selago (clubmoss).
Selaginella schmidtii (selaginella).
Woodsia glabella.

MOSSES.

Aulacomnium palustre (bunch moss).
Aulacomnium turgidum (bunch moss).
Brachythecium rivulare.
Bryum albicans (common moss).
Bryum bimum (common moss).
Calliergon alaskanum.

Calliergon cuspidatum.
Climacium americanum.
Dicranum bonjeani (pad moss).
Dicranum elongatum (pad moss).
Dicranum groenlandicum (pad moss).
Dicranum neglectum (pad moss).
Dicranum scoparium (pad moss).
Drepanocladus fluitans (fern moss).
Drepanocladus uncinatus (fern moss).
Funaria hygrometrica.
Hylocomium alaskanum (timber fern moss).
Hylocomium proliferum (timber fern moss).
Hypnum schreberi.
Leptobryum pyriforme.
Mnium glabrescens.
Paludella squarrosa.
Philonotis fontana.
Polytrichum commune (heath moss).
Polytrichum hyperboreum (heath moss).
Polytrichum juniperinum (heath moss).
Polytrichum piliferum (heath moss).
Polytrichum strictum (heath moss).
Polytrichum yukonense (heath moss).
Psilopilum arcticum.
Psilopilum glabratum.
Ptilidium ciliare.
Rhacomitrium lanuginosum.
Sphagnum angstroemii (sphagnum moss).
Sphagnum capillaceum tenellum (sphagnum moss).
Sphagnum fimbriatum (sphagnum moss).
Sphagnum girgensohnii (sphagnum moss).
Sphagnum magellanicum (sphagnum moss).
Sphagnum lindbergii (sphagnum moss).
Sphagnum plumosum (sphagnum moss).
Sphagnum riparium (sphagnum moss).
Sphagnum squarrosum (sphagnum moss).
Tetraplodon nimioides.

LICHENS.

Alectoria nigricans (black lichen).
Alectoria ochroleuca (black lichen).
Cetraria cucullata (Iceland moss).
Cetraria islandica (Iceland moss).
Cetraria islandica crispa (Iceland moss).
Cetraria juniperina (Iceland moss).
Cetraria juniperina terrestris (Iceland moss).
Cladonia alpestris (reindeer moss).
Cladonia amaurocraea (reindeer moss).
Cladonia bellidiflora (reindeer moss).
Cladonia coccifera (reindeer moss).
Cladonia coccifera pleurota (reindeer moss).
Cladonia coccifera stemmatina (reindeer moss).
Cladonia deformis extensa (reindeer moss).
Cladonia furcata (reindeer moss).
Cladonia gracilis elongata (reindeer moss).
Cladonia rangiferina (reindeer moss).
Cladonia sylvatica (reindeer moss).
Cladonia sylvatica sylvestris (reindeer moss).
Cladonia turgescens (reindeer moss).
Cladonia uncialis (reindeer moss).
Dactylina arctica.
Gyrophora arctica (broadleaf lichen).
Haematomma ventosum.
Icmadophila ericetorum (white pad-moss).
Lobaria linita.
Nephroma arcticum (ear lichen).
Ochrolechia tatarea.
Pertusaria bryontha.
Solorina crocea.
Stereocaulon paschale.
Stereocaulon tomentosum
Stereocaulon wrightii.

FUNGI.

Hydnum imbricatum (mushroom).
Polyporus elegans.
Scutula stercocaulorum.

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THE EFFECTS OF INBREEDING AND CROSSBREEDING ON GUINEA PIGS.

I. DECLINE IN VIGOR.
II. DIFFERENTIATION AMONG INBRED FAMILIES.

By Sewall Wright,
Senior Animal Husbandman in Animal Genetics, Animal Husbandry Division, Bureau of Animal Industry.

CONTENTS.

I. DECLINE IN VIGOR.

EARLIER VIEWS ON INBREEDING.

Inbreeding and crossbreeding are subjects on which there has been much discussion for centuries. The marriage customs of primitive peoples indicate that definite views on them were entertained long before the beginning of history. These views, however, were apparently different among different peoples, as the customs of some seem designed to prevent inbreeding, while the reverse seems true in other cases. A diversity of views continues to exist.

Livestock breeders have generally endeavored to prevent close inbreeding, holding that such breeding is likely to produce a progressive degeneration, exhibited by reduction in size, constitutional

vigor and fertility, and leading ultimately to the appearance of monstrosities. On the other side, however, we find that most of the modern improved breeds of livestock originated in rather close inbreeding of selected stock. Systematic livestock breeding began in England about the middle of the eighteenth century with the attempt of Robert Bakewell to improve the native Leicester sheep and Longhorn cattle. Bakewell had definite views on the characteristics which he wished to combine in his animals, but he departed most from the prevailing customs of his time in his use of close inbreeding for the purpose of fixing these desired characteristics. His methods were followed in the foundation period of most of the other British breeds. In the course of time, however, certain unfortunate characteristics, such as low fertility in the Duchess family of Shorthorns, came to be attributed to the inbreeding. At the present time there is much difference of opinion among practical breeders about the effects of inbreeding.

The remarkable increase in size and vigor which often follows the crossing of different varieties was noted by the early plant breeders. Darwin made carefully controlled experiments on the effects of self-fertilization and crossing of various plants. In general, those species with mechanisms facilitating cross-fertilization suffered an obvious decline in vigor when self-fertilized, while those without such a mechanism suffered no ill effects. He found that little or no improvement followed crossing within a self-fertilized strain, while marked improvement was the rule in crosses between such strains. In applying his results to livestock breeding Darwin pointed out that the advantage of close inbreeding in retaining characteristics might outweigh some loss in constitutional vigor.

Darwin's work on plants was followed by the experiments of Crampe and Ritzema-Bos with rats and of Weismann and Von Guaita with mice. The decrease in fertility and increase in sterility noted by all of these writers and the increased susceptibility to disease and the appearance of abnormalities noted by Crampe have long done duty as the stock examples of degeneration through inbreeding.

The problem has been attacked from a new viewpoint since the rediscovery of Mendel's law. The experiments of Castle, Moenkhaus, Hyde, Wentworth, and others with the fruit fly, *Drosophila melanogaster*, those of G. H. Shull, East, Hayes, Jones, Collins, and others with maize, and those of Miss King with rats have been rapidly bringing this subject into line with the current theory of heredity.

The experiments with guinea pigs described in this bulletin have given results which agree in the main with those of the authors mentioned above, although appearing at first sight somewhat difficult

) reconcile with the results in the only other recent extensive exper- nent on inbreeding of mammals, namely, those which Miss King otained with rats. It will be shown, however, that the two exper- nents are complementary rather than contradictory. It may e well to call attention to the excellent summaries of the present ate of knowledge on the subject to be found in Miss King's series papers and in "Inbreeding and Outbreeding" by East and Jones.

PLAN OF THE EXPERIMENTS.

An extensive investigation of the effects of inbreeding was planned 1906 by George M. Rommel, Chief of the Animal Husbandry ivision of the Bureau of Animal Industry. The work was com- enced in that year at the Experiment Station of the bureau at Be- esda, Md., with guinea pigs as material. Since 1911 the experiments ve been carried on at the Experiment Farm of the Bureau of nimal Industry at Beltsville, Md. Over 30,000 guinea pigs have en recorded. The work has been conducted successively by Ralph Carr, Dr. E. H. Riley, F. R. Marshall, and the writer. Essentially e same system of records has been kept throughout. On taking arge in September, 1915, the writer found the previous records excellent condition. In analyzing these and later data a great nount of tabulation and calculation has been necessary. The iter has been assisted successively by Walter J. Hall and Orson Eaton, to whose painstaking care in this laborious work the carry- ; through of the project is in a large measure due. All tabulations d calculations have been carefully checked.

HISTORY OF THE GUINEA-PIG STOCK.

Dr. E. C. Schroeder, superintendent of the experiment station at thesda, Md., has kindly furnished the following account of the ·ly history of the stock:

'he history of the station's stock of guinea pigs is as follows: When I took charge he experiment station of the bureau (at that time located at Benning Road and hteenth Street NE., Washington, D. C.), during the summer of 1894, I found on d about 250 to 300 guinea pigs, of all sizes and ages, about the history of which no ords were available. The general character of the animals indicated that some mpts had been made to breed special varieties, such as curly haired guinea pigs, te guinea pigs with black-smudged muzzles, long-haired guinea pigs, etc.

s there was a superabundance of other work which urgently required attention he station, I at once abandoned all attempts to breed guinea pigs of special types kinds, and made of the breeding pens a strict business project, with no other pose in mind than the production of a sufficient number of satisfactory animals for technical work of the bureau. I used the stock on hand, eliminating the fancy es as much as possible, because they are less satisfactory than the plain, vari- red, smooth-haired type for laboratory use.

ı the year 1895, as nearly as I can remember, I purchased a number of plain, nary male guinea pigs, which, after a lengthy period of quarantine, were intro- ed into the breeding pens.

Toward the latter part of the year 1896 it became evident that I would be able t move the experiment station from Benning Road and Eighteenth Street to som larger and more desirable place; hence I concluded that it would be wise to save a many young and vigorous pigs for breeding purposes as possible, and to start the guinea pig pens at the prospective new station with this young stock.

A new place for the station was found at Bethesda, Md., its present site, in May 1897, but it was not ready to be occupied until the following November, during which month the whole stock of guinea pigs was moved from Benning Road to Bethesda The stock at that time consisted of about 300 old breeders and about 400 young animals, unbred but specially selected for breeding purposes, also 100 to 150 young pigs.

During the journey from Benning Road to Bethesda, Md., a distance slightly more than 11 miles, a sudden, unexpected, heavy, cold shower of rain occurred, and many of the guinea pigs, though they were in cages and in a covered wagon, got thoroughly wet.

From 10 days to 2 weeks later the guinea pigs began to die at the rate of from 30 to 50 a day. The disease which caused the deaths was a combination of inflammation of the bowels and lungs. When the outbreak finally terminated just 63 guinea pigs were left alive, and of them 9 were in such hopeless condition that they were killed. This left 54 guinea pigs, varying in age from a few weeks to about 2 years.

The 54 guinea pigs are the stock to which all the guinea pigs that are now in the breeding pens at the experiment station, or that ever have been in the guinea-pig breeding pens at the Bethesda station, trace their origin.

The method of raising guinea pigs at the station has been always to select the best animals for breeding purposes, not only with reference to size and weight, but also with reference to smoothness of hair and productivity.

Unprolific breeders have always been eliminated from the pens as quickly as possible, and the progeny of such breeders have always been carefully avoided in selecting fresh breeders.

The total number of guinea pigs produced since the latter end of 1897 and the present time I can not give without spending several weeks searching our records. At present, however, the station is producing about 12,000 guinea pigs per annum, all of which trace their ancestry back to the 54 which were left after the disastrous outbreak of disease in the year 1897.

To judge from the information I have been able to obtain from various persons who are informed about guinea pigs, the stock we have at the station, so far as health, vigor, and productivity are concerned, in spite of the inbreeding to which they have been subjected, is, strictly speaking, very superior.

The beginning of the inbreeding experiment is described as follows in a report by Dr. E. H. Riley:

Investigations were begun in July, 1906, to study the effects of inbreeding when continued for successive generations. Guinea pigs were selected for this work because larger numbers could be housed and cared for with greater convenience than any other animal at our disposal, and, being prolific breeders, the data from succeeding inbred generations accumulated rapidly, thus enabling one to draw conclusions in a comparatively short time. Since large numbers of guinea pigs are used annually in the bureau laboratories, all stock which has served its purpose in the breeding experiment is readily made use of.

Two inbreeding tests were planned in this experiment. In Test No. 1 the foundation stock was line-bred for 12 years at the Bureau of Animal Industry Experiment Station. This foundation stock was selected from a group of 150 guinea pigs. The largest and most vigorous individuals of both sexes were selected for breeders. No attention was paid to color or color markings, except that no albinos were selected.

ecord was made of the coat color patterns as a means of identification. This record as later served as a means of noting certain family characteristics, which, in many ases, were transmitted to succeeding generations of inbred stock with quite uniform egularity. All animals of the foundation stock were between 5 and 6 months old hen mated.

Twenty-four females of uniform size and conformation were selected and numered consecutively from 1 to 24. The males were selected in a like manner and umbered in another series beginning with 1. The number of each of these females f the foundation stock was given to the family of guinea pigs which descended from er. Generation 1 is the progeny of the foundation stock, and is, therefore, not ibred. In order to follow the closest line of inbreeding, brother and sister of the ıme litter were mated. In all cases the best individuals in the litter were selected r breeders. Their progeny were selected and mated in a like manner. This method being continued, and at present (1913) individuals in a few of the families have een inbred for 13 generations. All breeders in each of the families have been inbred rough 4 generations.

In Family 4, parents were bred to their progeny: that is, sires were mated with eir daughters, granddaughters, etc., of each succeeding generation during the breedg period of their lives. In a similar manner dams were mated with their sons, andsons, etc., of succeeding generations.

In Test 2 of this experiment the animals of the foundation stock were unrelated to ch other. Some of the breeders were selected from the same general stock at the ureau of Animal Industry Experiment Station as were those in Test 1, but in all ses they were mated with stock which was obtained from a different source. The en stock was apparently as healthy and vigorous as the other. The foundation nales used in this test were numbered consecutively from 31 to 42, inclusive. The nilies were numbered in the same manner as those in Test 1. All animals were used, fed, and cared for in the same manner. Practically no change has been made the method of rearing our breeding stock since the experiment was started. The thods which we use are those which have been followed successfully for the past years by the Bureau of Animal Industry Experiment Station, where thousands of inea pigs are raised annually for laboratory purposes.

t was found that more satisfactory results could be obtained by having one male d only one female occupy each breeding cage, because frequently two females gave th to young at about the same time, making it impossible to tell to which female young belonged. In all such cases these mixed litters were eliminated from the periment. In a few instances young females became pregnant by their sires before y were weaned, which was at the age of 33 days. Young from these matings were o eliminated from the experiment.

According to this report, 35 families were started, 24 wholly from e line-bred stock of the Bureau of Animal Industry and 11 from a ss between this stock and guinea pigs obtained from a local aler. All were carefully selected, for vigor, from large stocks. all but one family, matings were made exclusively between full others and sisters. The data from Family 4, in which matings re made between parent and offspring, have not yet been analyzed. ven of the remaining 23 families in Test 1 (from the line-bred ck) went out of existence before the second generation was proced, for various reasons, such as the early death of the female or failure to produce living young of both sexes. Four of the 12 ilies in Test 2 failed for similar reasons, and another was disposed

of in the third generation because a skin disease had become established in it. These failures can not be ascribed to inbreeding.

There were thus 23 families with which the inbreeding experimen really started. One of these (Family 15) became extinct in 1911 Family 1 followed in 1914 and Families 3, 11, and 21 in 1915, leavin 18 families in existence at the end of 1915. Families 14, 19, and 3 became extinct before the middle of 1917. In the summer of 191 several other experiments had become so extensive that it seeme best not to attempt to maintain all of the inbred families. Fiv families—2, 13, 32, 35, and 39, were selected for perpetuation, whil the others were gradually eliminated. (Pls. I to VI.) The condition of the families in November, 1915, is shown in Table 1.

TABLE 1.—*Number of matings in each generation of inbreeding in each family on November 15, 1915.*

[The original matings are called the zero generation.]

Family.	Generation—										Number of matings.
	6	7	8	9	10	11	12	13	14	15	
2			4	10	11	6					31
7					4	3	1	3	1		12
9				1	1	4	6	4	1		17
13					6	13	15	5			39
14	1	1									2
17				1	1	3	6	6	3	1	21
18				1	3	3	4	4			15
19					3	4	1				8
20				5	7	5	1				18
23			1	4	4	2	1				12
24				2	2	2	1				7
31					1	4	6	4			15
32						3	4	12	7	1	27
34					2	1					3
35				1	2	5	10	11	8	1	38
36				1	5	11	6	2			25
38				1	0	6	7	3	1	1	19
39				1	7	18	14	2			42
Total	1	1	5	28	59	93	83	56	21	4	351

The 23 families which have been made the basis of analysis were descended from 23 different females, but are not so distinct from one another on the male side. Only nine males were in fact used in the foundation stock. Male 1 was used with Females 1, 2, 3, and 7 to found the families named from these females. Male 13 was the male ancestor of Families 9 and 11 and parts of Families 13 and 14. Male 2 was the male ancestor of the remaining lines in Families 13 and 14 and all of Family 15. Families 17 to 24 are all descended from Male 3; Families 31 and 32 from Male 9; Families 35 and 36 from Male 11, while Families 34, 38, and 39 had separate male ancestors. It may be seen that Families 13 and 14 are really composite and each might well have been treated as two families. In Family 13 the line descended from Male 2, began to decline after three genera-

tions, and produced its last litter in January, 1913, having reached the ninth generation. The family characters may in the main be considered to represent the large stock descended from Male 13. In Family 14 the two lines kept about the same ratio to each other in strength. The line from Male 2 was the strongest in numbers. It ran out in the tenth generation, while the line descended from Male 13 lasted only to the ninth generation.

The families other than 13 and 14 all descend from a single original pair but yet are of varying degrees of homogeneity. Some idea of the degree of homogeneity of the various families can be obtained from Table 2. This table shows the number of matings made in each family in two periods, 1906 to 1909, inclusive, and 1910 to 1914, inclusive, and the maximum percentage of these matings which can be traced back to a single mating in each generation of inbreeding. The original mating is called the zero generation.

The table reveals that certain families, such as 18 and 39, became dominated by a particular subfamily in their early history and remained so later. At the other extreme are families, such as 11, 14, 17, and 32, which remained split up into many subfamilies even through 1914. Most of the families became more homogeneous as time went on. Families 2 and 38 are extreme examples of the emergence of one subfamily into predominance. In a few cases (19, 24, 31, and 35) the most important subfamily in the first period became supplanted by another in the second. The most remarkable case of this sort, that of Family 35, is not fully brought out by the table. One of the four matings made in the second generation produced only 10 out of 59 matings of the third to seventh generations. Its only pair of descendants in the seventh generation produced 49 out of the 75 matings of Family 35 of the eighth to twelfth generations and produced all matings following the twelfth. This family has reached the twenty-third generation (1921) and now traces entirely to a single mating of the twelfth generation. There seems to have been no conscious effort to bring about the predominance of the descendants of the single mating of the seventh generation.

In interpreting the results in the various inbred families, it will be important to bear in mind that those in which one subfamily was predominant from the first or in which several subfamilies remained about equally important should maintain about the same average of hereditary characteristics throughout their history, while a marked change in the hereditary characteristics of the family as a whole need not be surprising in cases in which a subfamily, which is unimportant at first, later emerges into predominance.

TABLE 2.—*The relative homogeneity of the inbred families.*

[The number of matings made in each family from 1906 to 1909 (first line of each family) and from 1910 to 1915 (second line of each family) is given in the second column. The maximum percentage of these matings descended from a single mating in each generation is shown in the following columns. Change in the dominant subfamily is indicated by an asterisk.*]

Family.	No.	Generation. 0	1	2	3	4	5	6
1	11	100	91	27	....	....	....	....
	13	100	100	92	92	85	62	31
2	36	100	44	31	....	....	....	....
	65	100	89	89	86	74	57	34
3	41	100	63	44	....	....	....	....
	40	100	98	55	33	....	....	....
7	43	100	51	40	23	....	....	....
	77	100	69	65	47	....	....	....
9	26	100	96	46	19	....	....	....
	59	100	100	88	76	46	....	....
11	73	100	75	25	....	....	....	....
	71	100	72	45	....	....	....	....
13	67	55	54	28*	....	....	....	....
	94	100*	100*	80*	46*	....	....	....
14	42	50	48	....	....	....	....	....
	41	71	68	41*	....	....	....	....
15	23	100	44	....	....	....	....	....
	8	100	75*	....	....	....	....	....
17	38	100	63	42	....	....	....	....
	88	100	66	41	....	....	....	....
18	25	100	96	56	52	20	....	....
	62	100	100	76	76	37	....	....
19	19	100	95	88	32	....	....	....
	43	100	100	84*	84*	49*	....	....

Family.	No.	Generation. 0	1	2	3	4	5		7	8
20	23	100	61	52	13	....	....	....	....	....
	48	100	98	98	83	52	42	....	....	....
21	20	100	95	50	35	....	....	....	....	....
	96	100	100	100	89	48	....	....	....	....
23	12	100	83	50	25	....	....	....	....	....
	45	100	100	96	49	....	....	....	....	....
24	66	100	55	29	....	....	....	....	....	....
	63	100	59*	59*	29*	....	....	....	....	....
31	32	100	53	28	....	....	....	....	....	....
	64	100	53*	53*	53*	45*	....	....	....	....
32	103	100	62	23	....	....	....	....	....	....
	107	100	40	....	....	....	....	....	....	....
34	11	100	91	64	19	....	....	....	....	....
	34	100	100	100	44	....	....	....	....	....
35	45	100	98	29	....	....	....	....	....	....
	95	100	100	59*	59*	59*	59*	59*	58	33
36	47	100	96	47	....	....	....	....	....	....
	94	100	100	60	41	....	....	....	....	....
38	40	100	43	....	....	....	....	....	....	....
	61	100	92	92	92	49	....	....	....	....
39	14	100	93	86	71	64	29	....	....	....
	77	100	100	100	100	100	56	56	31	....
	....	....	....	....	....	....	....	....	....	....
	....	....	....	....	....	....	....	....	....	....

From 1906 to 1911 the inbred stock, as already stated, was kept at the bureau Experiment Station at Bethesda, Md., with many other guinea pigs raised for pathological experiments. In 1911 the inbred stock was taken to the experiment farm at Beltsville, Md. Shortly before moving, 40 pairs of normally bred guinea pigs were selected on the basis of vigor and set aside as a control stock to be maintained without inbreeding. They were from the same stock from which Families 1 to 24 and the original females of Families 31 to 39 were derived. They had, however, been maintained up to 1911 without records. This control stock was called Experiment B. It has been kept at Beltsville since 1911 under the same conditions as the inbred families except that matings as close as those between second cousins have been avoided.

SYSTEM OF MATING, CARE, AND FEED.

With rare exceptions, the matings in the inbred families have been made between litter mates at the time of weaning at 33 days. This was to avoid mistakes in identity which would make the strictness of the inbreeding doubtful. Females occasionally are sufficiently mature at 33 days to bear litters sired by their own sire at about 100 days of age. They do not appear to suffer ill effects, and as the males do not become mature until over 2 months of age, the system of breeding followed is not believed to be injurious to the animals to an appre-

ciable extent. Most but not all of the matings in the control stock were made between immature guinea pigs. A single pair has been kept in each pen as already stated, except for cases in the early generations.

Large wooden pens, 23 by 16 by 29 inches on the inside, were used until 1916. They had got into rather bad condition by this time and had become infested with bedbugs. They were replaced in December, 1916, by metal pens, 16 by 14 by 24 inches, with removable trays for ease in cleaning. Whether the improvement in cleanliness and freedom from bedbugs compensates for the smaller amount of room for exercise and the greater difficulty in maintaining an even temperature in winter is not certain. In any event, experiments conducted in different years must be compared with due caution.

The guinea pigs have been given oats and fresh water every day. Green feed is supplied three times a week and hay once a week when the pens are cleaned. Green oats and fresh grass in spring and summer, and cabbage and kale in fall and winter have been used most successfully as green feed. The greatest difficulty in procuring good green feed comes in late winter and early spring, after other winter conditions have depressed the stock. All records indicate that the stock is in the poorest state at this time. Conditions are also better as a rule in the early part of summer and in fall than during the hot weather in July and August.

THE DATA RECORDED.

All litters are recorded on the day on which they are born, except that litters born on Sunday or a holiday are recorded on the next day. At birth the date, pen, number, sex, color, and weight are recorded for each young one. Drawings are made of the coat pattern of each guinea pig in a rubber-stamp outline. The variety of the colors, including intense and dilute agouti, black with red, yellow, or cream spotting, and albinism, together with the almost endless variety in the tricolor pattern, make color and pattern an almost certain means for the identification of individuals. Ear punches are also used as a help to identification. All mated animals are identified at death to insure that no confusion has occurred in the matings. Each of the young is weighed at the ages of 3, 13, 23, and 33 days as well as at birth. Up to 1916 the mated animals were weighed when 1 year old. Since 1917 more frequent weighings have been made.

THE CHARACTERS STUDIED.

Possible effects of inbreeding have been looked for in age of maturity, fertility, rate of growth, mortality among the young, resistance to tuberculosis, sex ratio, the production of monstrosities, and coat color.

Under the head of fertility, both the size and frequency of litters have been considered. Little attempt has been made to distinguish complete and partial sterility, as cases of complete sterility have been rare and uncertain in all stocks. The failure of a mating to produce litters has usually been due to the early death of one member of the pair.

The data on the rate of growth up to the age of weaning (33 days) are naturally much more extensive than those on later growth, and have been studied in more detail. The principal characters which are used in this connection are the weight at birth of all of the young born, the birth weight of those which survive to 33 days, and the gain between birth and 33 days.

The losses among the young are considered under two heads, death at or before birth and death between birth and weaning. The characters used are the percentage born and found alive and the percentage raised to 33 days of those born alive. The product of these two, namely, the total percentage raised, is also used.

LIFE HISTORY.

Guinea pigs are born in litters of 1 to 9. Litters of from 2 to 4 are most common, and litters of more than 6 have been decidedly rare in the present work. The young are born in a very advanced state of development, with thick fur, open eyes, and the ability to run about at once. They soon begin nibbling at the leaves of cabbage or other green food in the pen. They are, in short, rather better able to take care of themselves from the time of birth than the young of any other familiar domesticated mammal. They grow rapidly and reach about half the adult weight when between 2 and 3 months of age. The final weight is nearly reached at a year, but there is slow growth for a longer time. Guinea pigs are in their prime between 1 and 3 years. After reaching 3 years there seems to be a distinct decline. The present experiments, however, have not been designed to study longevity, as matings have often been disposed of to make room for those of a later generation. The oldest dam recorded had reached 47 months. The average age of dams has been between 14 and 16 months. One female is reported to have died at an age of 59 months. Her last litter was born at 38 months.

Sexual maturity is reached early. In nearly every family and experiment there have been a few cases in which females have had young when about 100 days old. As the gestation period is about 68 days, this means that these litters were sired by the dam's sire before she was weaned at 33 days. The minimum age at which a male may sire a litter seems to be about 60 days, although we have one apparently reliable record at about 48 days (litter born at 117 days).

The average age under ordinary conditions seems to be about 3 months, bringing the first litter between 5 and 6 months.

The birth of a litter is followed at once by an œstrus period. In 50 to 60 per cent of the matings in a vigorous stock, fertilization takes place at this time, and one litter follows another after an interval of 65 to 74 days. If fertilization does not take place, there is a period of about 17 days before the next œstrus, and recurrence thereafter at about this period. The average interval from one litter to another, if there is no delay, is about 69 days (68.93 ± 0.04 in 1,332 cases among inbreds and controls in which the interval was between 65 and 74 days). The true gestation period would of course be slightly shorter. The gestation period is subject to much variation, its standard deviation, judging by that of the intervals between litters, being almost two days (1.91 ± 0.03 in the above data). The most important cause of variation is the size of litter. Large litters are born earlier than small ones. The correlation between size of litter and interval in the data mentioned above was -0.457 ± 0.015. Under unfavorable conditions the average gestation period is slightly shorter than under favorable conditions. Young born before 65 days are seldom raised, or even born alive.

FERTILITY.

The number of litters produced per year depends in the main on whether many of the litters succeed one another without delay, which doubtless depends in part on whether or not ovulation takes place immediately after the birth of the preceding litter. Evidence which will be presented later, however, shows that the sire is more apt to be responsible than the dam for irregularity in this respect. The most important factors are associated with the conditions at this time. If the preceding litter is small, if environmental conditions are improving (as in April and May as a rule), or if the female is above the average weight for her age, there is considerably more likelihood that a second litter will start on its career at once than if, for example, a large litter is born in December leaving the dam much under weight. The age of the dam, at least up to 3 years, does not seem to be an important factor. There is, however, a trifle more regularity between 1 and 2 years of age than before or after. Regularity or irregularity is not characteristic of particular matings to any marked extent. The correlation between successive intervals, classified as more or less than 77 days, came out virtually zero in the control stock (-0.01 ± 0.03). This excludes both heredity and condition of health over long periods of time as important factors. Other results show the small importance of heredity in particular cases, the correlations between parent and offspring matings, in litters per year, being insignificant in both controls and inbreds. On the other hand, as we

shall see later, by comparing the averages of whole families significant differences can be found which must be attributed to heredity.

For the purposes of the present work, frequency of litter has been measured in a somewhat rough way. Matings are entered in a table under the month in which the male reaches 4 months of age (an average of 3.5 months) or under the month following that in which the mating was made if the male was already more than 3 months old. The mating is dropped from the table the month after the death or disposal of the female. The number of litters produced by a given group of matings, divided by their effective duration in years, as calculated by the above method, gives the average number of litters produced by a mating in a year. In comparing experiments it must be borne in mind that difference in the age of maturity as well as in the regularity in producing litters may be responsible for observed differences in frequency of litter as calculated by this method.

The production of a given size of litter, as in the case of frequency, is only to a slight extent characteristic of matings. The correlation between successive litters produced by the same mating among the controls was -0.011 ± 0.023 and that between litters which were not successive was $+0.064 \pm 0.014$. Similarly insignificant correlations were obtained from extensive tabulations among the inbred families. The correlation between parent and offspring in the average size of the litters produced is in all cases so small as to be of doubtful significance. Here, again, the only satisfactory evidence of heredity is found on comparing different inbred families raised under identical conditions.

Variations in environmental conditions have a marked influence on size of litters. The average is usually higher in summer and fall than in winter and spring. In the controls (first 112 matings, 588 litters) averages of 2.75, 2.84, 3.26, and 3.16 were found for successive periods of three months beginning with January to March. This decrease in the average size of litter under unfavorable conditions seems to be due to a reduction of large litters to medium-sized ones (perhaps by death and absorption of some of the embryos), rather than to increase in the percentage of small litters. The percentage of litters of 1 and 2 in these data was found to be nearly constant at all seasons of the year, but the percentage of litters of three increased greatly in winter and spring at the expense of litters of 4 or more, litters of 3 rising from 25.5 per cent in summer to 45.9 per cent in spring. In such of the inbred families as were characterized by a markedly smaller average size of litter the percentage of small litters was much greater than in the controls. Such inbred families under good conditions might produce litters of the same average size as the controls under poor conditions, but the distribution of litter

sizes has been strikingly different in these cases. The average size of litter among the controls born in the years 1911 to 1916 under the unfavorable conditions from January to June was 2.77. The average for the eight poorest inbred families during the months July to December in 1906 to 1910 was nearly the same, 2.74. The difference in distribution may be seen in Table 3. It appears that inferior heredity reduces the size of litter in a different way from inferior environmental conditions.

TABLE 3.—*Percentage of litters of each size in two stocks of guinea pigs—a vigorous stock under poor conditions and a weak stock under good conditions.*

Kind of stock.	Number of litters.	Average size of litters.	Percentage in litters of 1 to 6.					
			1	2	3	4	5	6
Controls (conditions unfavorable)	386	2.77	11.4	27.5	40.7	15.0	4.4	1.0
8 inbred families (conditions favorable)	372	2.74	16.9	31.7	24.5	16.4	8.6	1.9

The age of the dam has an influence on the size of the litter, but not an important one. First litters are smaller than later ones on the average (2.77 compared with 3.05 in the first 112 matings of the controls). This difference, however, exists mainly because first litters are especially apt to be born in winter and spring. Most matings have been made in summer and fall, when conditions are favorable, and the first litter, born when the dam is about 6 months old, has thus been smaller on the average than litters born at 12 months or 24 months, but not much smaller than litters born in the neighborhood of 18 months. Females from 1 to 2½ years old, however, produce slightly larger litters than younger or older females, apart from the seasonal complication.

Among the controls, litters which follow others without delay are slightly larger than those born after a long interval (3.16 compared with 2.91 in the tabulation referred to above). Presumably the same causes which were favorable to immediate fertilization were favorable also to a large size of litter. Curiously enough, a tabulation among the inbreds born in 1916 gave a contrary result. The average was 2.22 after a short interval and 2.46 after a long one. In this case only 36 per cent of the litters were born after an interval of less than 75 days as compared with 56 per cent in the controls in the former tabulation. Apparently in this case the advantage of the recuperation furnished by the delay outweighed the unfavorableness of the conditions which was indicated by the mere fact of a delay.

Taking the record of each mating as a whole, there is no significant correlation between the size and frequency of litters.

All the factors which have been considered—constitutional vigor, heredity, season, age of dam, and interval since preceding litter—if combined, determine the size of litter only to a small extent, probably less than one-tenth. The determination of the size of any particular litter must be due largely to rather temporary conditions. The immediate direction of change in the condition of the dam at a critical period, for example, may be the important factor. From the standpoint of the condition of the female, during an appreciable period of time, it appears that variations in size of litter are largely a matter of chance. The most vigorous female may have a litter of 1 under what seems the best of conditions, and a litter of 4 may be born when everything seems opposed.

MORTALITY AMONG THE YOUNG.

Guinea pigs may be born dead for a variety of reasons. A large percentage of those classified as born dead are born prematurely, and the average weight is much less than that of those born alive. There are, however, not infrequent cases of animals which are unusually large at birth, but are found dead apparently because of difficulties in parturition. Many of those classified as born dead undoubtedly were born alive but died before being recorded. In general the percentage born alive obviously depends largely on the health of the dam. Unfavorable environmental conditions act in the main indirectly on the young. The inherent vigor of the young, however, plays some part, as is shown by the improvement in the percentage born alive when inbred females are mated with unrelated males, instead of with their brothers, a point which will be discussed in a bulletin to follow.

The percentage of the young which is raised among those born alive also depends much on the health of the dam, but to a less extent than the percentage born alive. There have been cases in which the young reached 33 days largely through their own efforts, the mother having died a few days after their birth. Environmental influences act on the young directly as well as indirectly in this case. The inherent vigor of the young counts for much. Thus we find that the percentage raised of those born alive shows a more marked improvement when inbred females are crossed with unrelated males instead of with brothers than is the case with the percentage born alive.

Both of these percentages reflect closely the changes in environmental conditions. Inadequate or inferior green feed causes a large number of stillbirths and an increased mortality among the living young. A change from alfalfa to timothy hay has been observed to have the same effects. The records are usually much better in both respects in summer than in winter. In years in which one of

these percentages was high, as 1910 and 1914, the other was also high, the same years showing, moreover, high records in size and frequency of litter and rate of growth.

It will be shown later that there are significant differences among the inbred families, differences which must be hereditary. It will be shown also that success in bearing living young is not correlated with success in rearing them. Genetically the constitutional vigor of the young themselves and the qualities of the dam which favor their successful rearing seem to be largely independent of the qualities which insure against stillbirth.

The size of litter naturally makes a difference in the percentages born alive and reared. The effect, however, is different in different stocks. In the vigorous control stock there was not much difference even up to litters of 6. Litters of 3, however, were most successful in both respects, with litters of 2, 4, and 5 following closely. In the inbred families the most favorable size of litter has shifted to 2 or even 1, and litters of 3 or more are at a disadvantage. Apparently in a vigorous stock a litter of 1 is itself so much of an indication of lack of vigor that smaller percentages are born alive and reared. This effect is not a seasonal one, since litters of 1 and 2 were hardly more numerous in winter than in summer among the controls, while litters of 3 were much more numerous in winter.

There is no appreciable difference between males and females in the percentages born alive and reared. Among the controls (112 matings) 87.1 per cent of the males and 87.5 per cent of the females were born alive. Among those born alive, 84.9 per cent of the males and 85.4 per cent of the females were reared. Equally insignificant differences, reversing, however, the slight advantage of the females, were found among the inbred families.

The age of the dam has little bearing on the percentage born alive or reared, except as it is correlated with seasonal changes. The cyclical tendency toward maxima at 12 and 24 months and minima at 6 and 18 months, noted in the case of size of litter, is also pronounced in the mortality percentages.

There is naturally a strong tendency for the young in the same litter to share the same fate.

RATE OF GROWTH.

The birth weight of guinea pigs varies greatly. Animals which ultimately reach maturity may have weighed anywhere from 40 to 150 grams at birth. The average is about 80 grams. About half fall between 64 and 91 grams. There is little difference between the sexes. An extensive tabulation among the controls gave a difference of only 2.7 ± 0.8 grams in favor of the males. There was a difference of 11.1 ± 2.6 grams in favor of the males at 33 days. The males con-

tinue rapid growth longer and are much heavier at 1 year. A tabulation among the inbred families (1910 to 1914) gave averages of 888 grams and 763 grams, respectively, for the weight at a year in males and females.

A little experience is enough to demonstrate that the size of litter is a very important factor in determining the variations in birth weight. Single guinea pigs are not only conspicuously larger as a rule but also have longer hair and are more active than those in large litters. The correlation between the size of litter and mean weight of litter mates came out -0.658 ± 0.007 as the average of determinations in 11 inbred families and in the controls. The correlation between size of litter and individual birth weights is, of course, somewhat less (about -0.57). The correlation between mean birth weight of litters and interval since last litter was $+0.533 \pm 0.013$ in the cases in which this interval was less than 75 days. The correlation between interval and litter size was -0.457 ± 0.015, as previously stated. Analysis of these and other data shows that size of litter has considerably more effect on birth weight through its effect on rate of growth than by merely determining a longer or shorter period of growth, a conclusion contrary to that reached by Minot.[1] The analysis further indicates that the rate of growth is affected by the general condition of the dam even more than by the size of the litter. The hereditary potentialities of the fetus itself are in addition important factors in a crossbred stock.

Hereditary differences are, however, relatively unimportant in a random-bred stock. The correlation between the mean birth weights in successive litters was found to be -0.051 ± 0.023 in the control stock and that between litters which were not successive was $+0.058 \pm 0.014$. Nevertheless, it will be shown later that hereditary variation was sufficiently great in this stock to permit the isolation of marked differences among the inbred families derived from it.

Even when all of the above factors are constant, as within a litter produced by an inbred stock, there may be considerable variation. There was an average standard deviation of about 10 grams within litters of any given size from 2 to 7 in the control stock, after making due corrections for the small numbers. The standard deviation of the mean birth weights of litters, again making the necessary corrections, was of about the same size, declining from 13.7 in litters of 2 to 7.4 in litters of 7. Thus in this case variations within litters and among litters means are about equally important. Only an insignificant part of the variation within litters is genetic in the controls as

[1] Minot, C. S., 1891. Senescence and rejuvenation. Jour. Physiol. v. 2 p. 97–153.

FIG. 1.—MALE OF FAMILY 2, BELONGING TO THE TWELFTH GENERATION OF INBREEDING.

FIG. 2.—FEMALE OF FAMILY 2, FULL SISTER OF THE MALE SHOWN ABOVE.

This family is characterized by frequent but rather small litters, heavy mortality at birth but great vitality and longevity thereafter. It is second in resistance to tuberculosis.

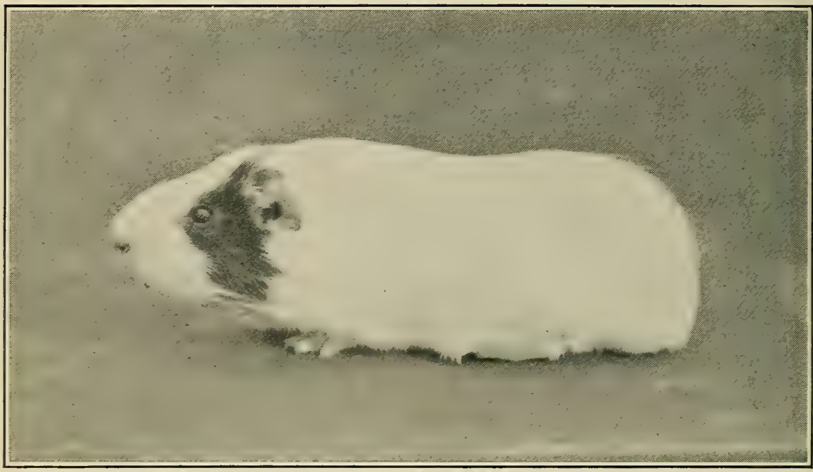

FIG. 1.—MALE OF FAMILY 13, BELONGING TO THE EIGHTEENTH GENERATION OF INBREEDING.

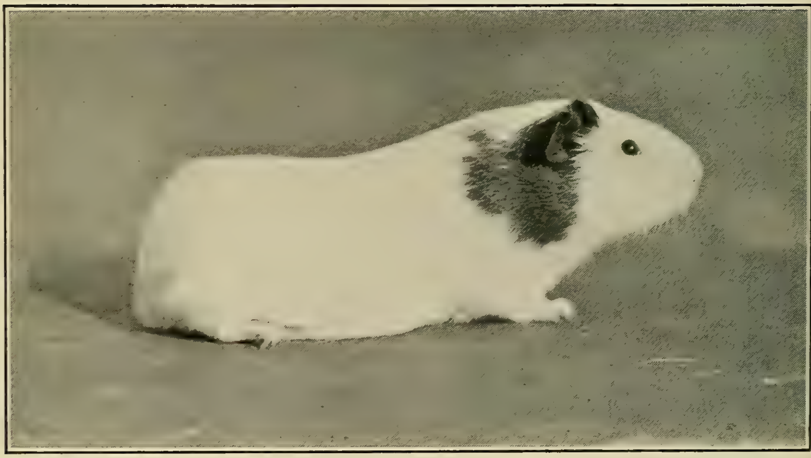

FIG. 2.—FEMALE OF FAMILY 13, FULL SISTER OF THE MALE SHOWN ABOVE.

The heaviest animals and the largest litters come in this family. It is above the average in most other respects but is next to the poorest in resistance to tuberculosis. The large amount of white is characteristic.

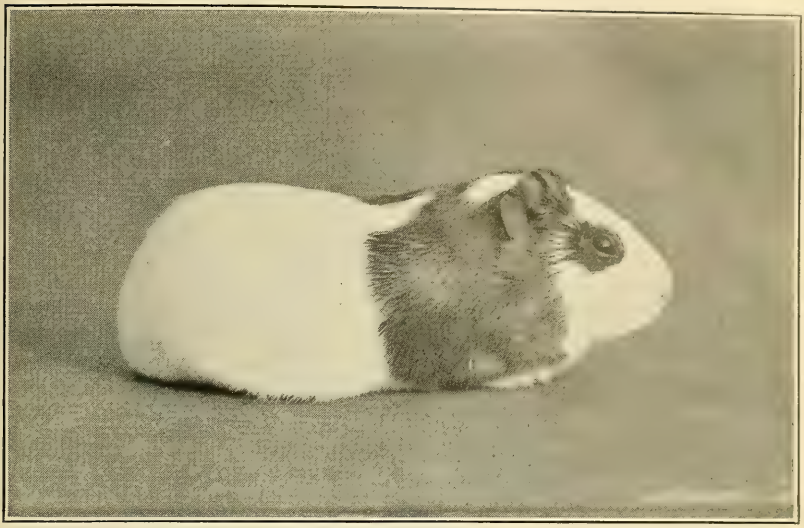

FIG. 1.—MALE OF FAMILY 32, BELONGING TO THE SEVENTEENTH GENERATION OF INBREEDING.

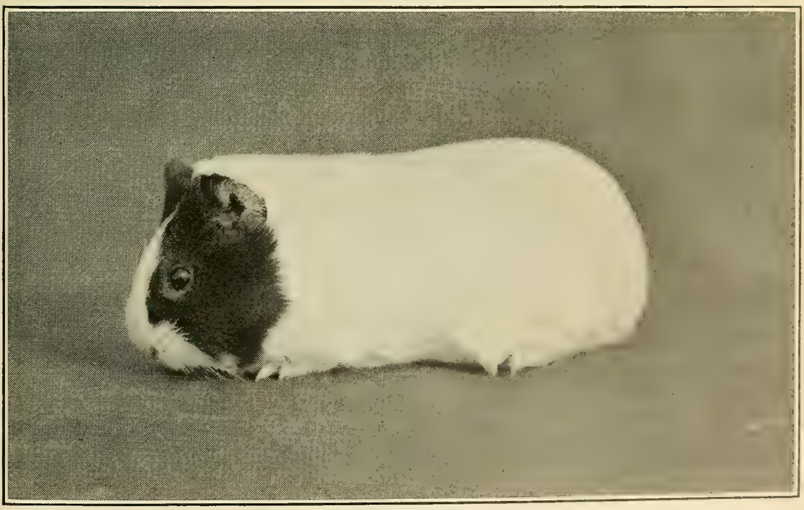

FIG. 2.—FEMALE OF FAMILY 32, FULL SISTER OF THE MALE SHOWN ABOVE.

This family is below the average in most respects. It contrasts with Family 13 in its light average weight and small litters, but resembles that family in the large amount of white in the coat and in its only very slightly greater resistance to tuberculosis.

FIG. 1.—MALE OF FAMILY 35, BELONGING TO THE NINETEENTH GENERATION OF INBREEDING.

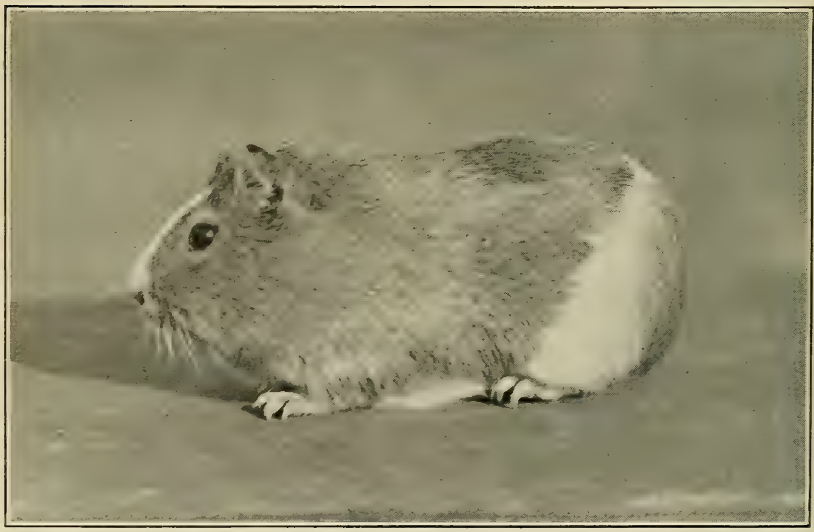

FIG. 2.—FEMALE OF FAMILY 35, FULL SISTER OF MALE SHOWN ABOVE. NOTE THE LARGE AMOUNT OF NONGENETIC VARIATION IN AMOUNT OF WHITE.

Inbreeding has gone further in this family than in any other, possibly because it is above the average in nearly all elements of vigor. It is much the most resistant to tuberculosis.

FIG. 1.—MALE OF FAMILY 39, BELONGING TO THE THIRTEENTH GENERATION OF INBREEDING.

FIG. 2.—FEMALE OF FAMILY 39, FULL SISTER OF THE MALE SHOWN ABOVE. THE SMALL AMOUNT OF WHITE AND THE SWAY BACK ARE CHARACTERISTICS FIXED IN THIS FAMILY.

Other characteristics are the greatest success in bearing young alive, but lack of success in rearing them, irregularity in producing litters, and the greatest susceptibility to tuberculosis.

FOUR GENERATIONS OF FAMILY 35.

The young pair at the right is descended from 19 generations of matings of brother with sister. Their parents, grandparents, and great-grandparents were all found to be alive and are shown in the picture. There is little if any genetic variation left in this stock. The variation in pattern, which persists, seems to be due to nontransmissible irregularities in development.

shown above. Most of the variation within litters thus must be due to such a cause as position in the uterus.

Seasonal conditions have a marked effect on birth weight through their influence on the condition of the dam. The age of the dam is not an important factor.

The gain in weight between birth and 33 days is affected by the same factors which affect the prenatal rate of growth, namely, size of litter, condition of dam, and heredity.

The correlation between gain and size of litter in the same data as those used above was -0.381 ± 0.011. That between gain and interval was $+0.283 \pm 0.018$. There is naturally considerable correlation between birth weight and gain, the figure being $+0.533 \pm 0.009$. Heredity plays a larger part than in the case of birth weight, and the condition of the dam a smaller one. This was shown, as in the case of the percentages born dead and reared, by the relatively greater improvement in gain than in birth weight among the offspring of inbred dams when mated with unrelated males instead of with brothers.

Hereditary variation, however, is not of much importance within the control stock. The correlation between the mean gain of successive litters was $+0.221 \pm 0.026$, and that of litters which were not successive was $+0.062 \pm 0.016$. Common environmental factors may play a part in the former case as well as heredity.

Comparison of the gains made in different seasons and years demonstrate the importance of differences in environmental conditions in the present experiments.

The effect of size of litter on the early growth is soon lost. There is no correlation between size of litter and weight at a year among the inbreds ($r = +0.010 \pm 0.018$, in males; $r = -0.029 \pm 0.019$ in females). The common influence of heredity, however, is seen in the correlations of $+0.395 \pm 0.031$, $+0.375 \pm 0.024$, $+0.374 \pm 0.035$, and $+0.494 \pm 0.051$, between weight at birth and weight at a year in litters of 2 to 5 respectively among males. The correlations were smaller among females ($+0.339 \pm 0.032$, $+0.160 \pm 0.029$, $+0.187 \pm 0.041$, $+0.134 \pm 0.070$), owing, doubtless, to the greater unreliability of their weights at a year. It was shown in an earlier paper [2] that the correlation of $+0.375 \pm 0.024$ for males in litters of 3 was in part due to a correlation of $+0.630 \pm 0.083$ between average birth weight and average year weight among 24 inbred families (including Family 4) and in part to an average correlation of $+0.308 \pm 0.026$ between birth weight and year weight within a family. The value

[2] Wright, S. 1917. The average correlation within subgroups of a population. Proc. Wash. Acad. Sci v. 7, p. 532-535.

for the correlation of family means is doubtless wholly due to the common factor, heredity of size. The correlation within families is probably due in part to genetic differentiation within the families and in part to environmental causes.

SEX RATIO.

Sex follows closely the laws of random sampling in guinea pigs. The sexes have been produced in nearly equal numbers in all experiments. Thus, in the tabulation of the controls born in 1906 to 1920 there were 2,051 males and 2,007 females. Among the inbreds born in the same years were 12,831 males and 12,529 females. Extensive tabulations have given no indications of any connection between sex ratio and size of litter or season or year of birth. In every other character considered, by far the highest records were obtained in the year 1910. The percentage of males in this year was 50. Again, if there were any important extraneous causes determining sex, litters exclusively of males and exclusively of females should be more numerous than expected by the laws of random sampling. The actual numbers, however, have been very close to those expected; (580 males and females were born in litters of 2 to 5 containing only one sex, during 1916 and 1917, where 590 was the expected number.) The only contrary indication was in an apparent differentiation of the inbred families with respect to sex ratio, which was somewhat greater than would be expected by random sampling.

INDEXES FOR GROWTH AND MORTALITY.

The purpose in going into the causes which affect the various characteristics of guinea pigs has been to bring out the precautions necessary in studying the effects of inbreeding and crossbreeding upon them.

Size of litter, for example, has such important effects on the rate of growth and the mortality among the young that it would be unfair to compare such characters as the average weight at 33 days and the percentage raised, in stocks with different average sizes of litter. It is, however, desirable to obtain a single figure to express the record of each experiment with respect to each character. Accordingly, indexes have been calculated for the weights and mortality percentages for each stock, based on a fixed number of litters of each size. The averages of litters of 1, 2, 3 and 4 have been assigned weights of 1, 3, 4, and 2, respectively, the resulting sum being divided by 10. An index in a given stock is thus the average which would be obtained if 100 guinea pigs were picked at random from litters of 1, 300 from litters of 2, 400 from litters of 3, and 200 from litters of 4. The different weights assigned to the different sizes of litter measure

roughly the relative reliability of the averages. The number of litters of each size produced by the inbred families between 1906 and 1915 was as follows:

Size of litter.	Number.	Size of litter.	Number.
1	1,187	5	387
2	2,230	6	100
3	2,253	7	19
4	1,111	8	2

Data for later years are discussed in more detail in Bulletin 1121. There was a considerable smaller average size of litter than in the preceding years, which made a different index desirable. In this bulletin the same index is used for 1916 to 1920 as in the earlier years.

In the above data we see that litters of 1, 2, 3, and 4 occurred approximately in the ratio of 1 : 2 : 2 : 1, while large litters were much less numerous. The young in these litters were in the ratio 1 : 4 : 6 : 4. Use of the latter ratio would give too much importance to the larger litters, because of the obvious tendency for litter mates to resemble each other in birth weight, rate of gain, and fate. On the other hand, averages based on a given number of litters of 4 are more reliable than ones based on the same number of litters of 1. In the case of birth weight it has been noted that variations within litters and variations among the means of litters of a given size are about equally important. It has accordingly seemed best to adopt a compromise between the ratio based on litters and the ratio based on individuals. The ratio 1 : 3 : 4 : 2 has thus been arrived at. Where two stocks differ consistently in all sizes of litters it makes little difference what ratio is used in calculating indexes. Where they do not differ consistently, no index is of much value.

ENVIRONMENTAL CONDITIONS.

Tabulations of the various characters among the inbred families were originally made according to generation. The results, however, were irregular. Family 2, for example, reached its highest point in size of litter in the fifth generation of inbreeding. The high point in Family 23 was a generation earlier. The variations in other characters tended to agree with those for size of litter in a given family. A study of the curves suggested that much of the variation was probably due to variations in conditions from year to year. In order to interpret the results with safety it is necessary to bring out as fully as possible all causes of change other than inbreeding. Thus tabulations were made with the year instead of the generation as a unit. As all inbreeding began in 1906 and the original matings produced no young after the spring of 1907, each year can safely be assumed to represent a higher average degree of inbreeding than the preceding year.

Table 2 gives the number of matings in each generation of each family near the end of 1915. The average number of brother-sister matings in the ancestry of the young from these matings was 11.4.

Sex has a slight influence on birth weight and slightly more influence on gain to weaning. These effects, however, are so small in comparison with those of other causes of variation, and the ratio of the sexes is so close to equality in all experiments, that it has not seemed necessary to make tabulations of these characteristics with the sexes separate. On the other hand, in studying the growth after weaning, separate averages must be made for the males and females. Similarly the influence of sex on the juvenile mortality can be neglected, although very important in dealing with the death rate of adults.

The age and previous record of the dam have been found to have slight effects on some of the characteristics studied, but so slight that they can safely be neglected in comparing different experiments with each other.

Summing up, size of litter and environmental conditions, together with sex, in the case of adult characteristics, are the only factors for which constant allowance must be made. Tabulations have thus been made separately for each size of litter and for each year. A method by which the averages for different sizes of litters are combined in a single index has been described.

CHANGES IN THE INBRED AND CONTROL STOCKS.

The averages for each character in each size of litter in the inbred and control experiments are given by years in Tables 6 to 22. The indexes for each year, calculated as described above, are also given. The results are presented graphically for the indexes in Figures 1 to 11.

Turning first to the indexes, we see that there are considerable fluctuations from year to year. These fluctuations are evidently significant, being based on quite large numbers. There is, moreover, not only a remarkable degree of parallelism between the fluctuations among the inbreds (A) and the controls (B) in most respects, but also a high degree of parallelism between the fluctuations of different characters. In the year 1910 all characters were at a maximum. There was a sharp drop in 1911, improvement in 1912, decline in 1913, and a marked improvement in 1914. There was a pronounced decline in 1915, continued to 1918, and followed by a rise in 1919. The only departure from parallelism that requires comment is the much greater decline in the mortality curves in 1916 and 1917 among the inbreds than in the control stock. The marked decline in 1916 was undoubtedly due to the severity of the winter of 1915–16 and a shortage of green feed in winter and early spring. The decline in the inbreds, however, is probably somewhat exaggerated, since the pens which they occupied were decreasing in number during 1916 and 1917

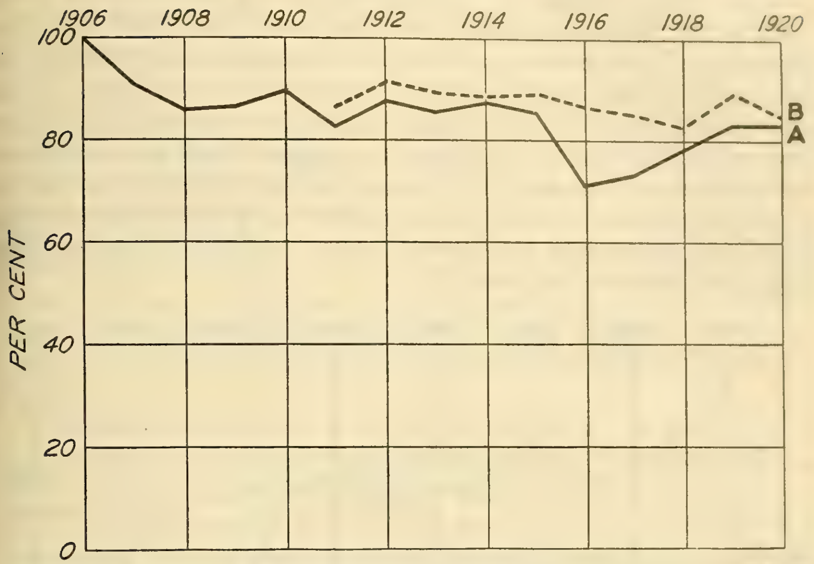

FIG. 1.—The percentage born alive among the inbreds (*A*) and controls (*B*) in successive years 1906 to 1920. Correction made for effect of size of litter by assigning weights of 1, 3, 4, and 2 to the averages for litters of 1, 2, 3, and 4, respectively.

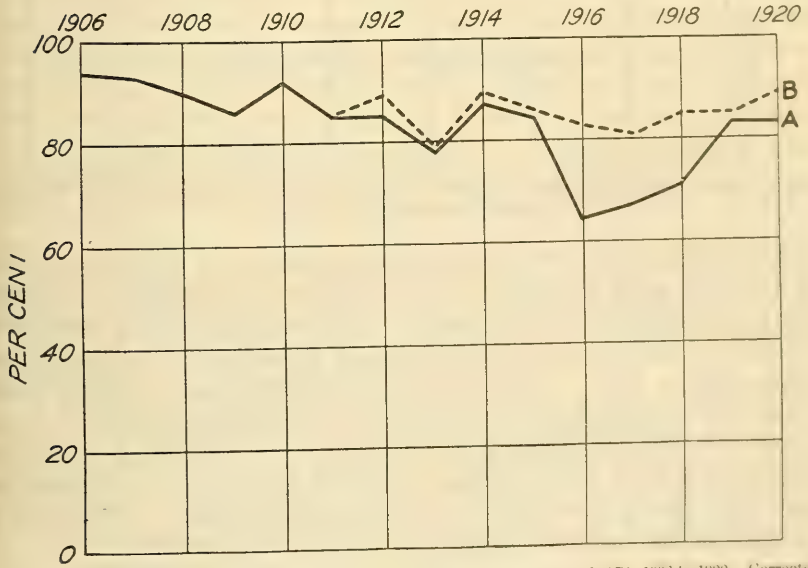

FIG. 2.—The percentage raised of those born alive. Inbreds (*A*) and controls (*B*), 1906 to 1920. Corrected for effect of size of litter as in Figure 1.

as room was made for other experiments. This meant that an unusually large percentage of the inbred young were born in both years in the winter and spring months, when conditions were unfavorable. Unfavorable conditions have a more immediate effect on the mortality among the young than on other characters. This explanation, however, is not wholly adequate to account for the disproportionate decline in the inbreds as compared with the controls in one set of characters only. It therefore seems probable that the inbreds had reached a critical stage, in which a given change for the worse in environmental conditions actually produced a disproportionately great effect on the mortality.

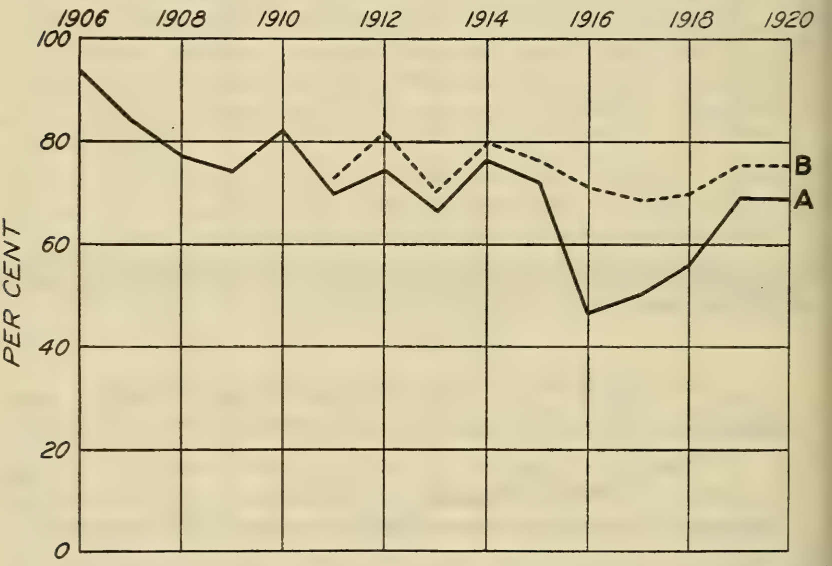

FIG. 3.—The percentage raised of all young born. Inbreds (*A*) and controls (*B*), 1906 to 1920. Corrected for effect of size of litter as in Figure 1.

Disregarding the fluctuations from year to year, a downward trend is apparent in all characters. The trend can be measured by fitting the best straight line to the graphs. This has been done by Pearson's method of moments for the characters given below, for the years from 1907 to 1915. It is, of course, recognized that a straight line would not be appropriate for changes in percentages over a very wide range. A uniform decrease in the ability to rear young would be represented by a curve starting from 100 per cent as an asymptote and falling away ever more rapidly for some distance. Fitting with a straight line, however, brings out the fact of a decline.

TABLE 4.—*Linear equations representing the trend in the inbred stock relative to each characteristic.*

(In these equations y is the measure of the character in question and x is the number of years from 1906.)

Size of litter	$y= 2.885-0.043x$
Litters per year	$y= 4.210-.110x$
Young per year	$y= 12.092-.450x$
Percentage born alive	$y= 88.27-.29x$
Percentage raised of those born alive	$y= 92.10-1.04x$
Percentage raised of all born	$y= 81.30-1.16x$
Birth weight of young raised (grams)	$y= 86.17-.19x$
Gain, 0 to 33 days (grams)	$y=163.70-1.96x$
Weight at 33 days (grams)	$y=249.87-2.15x$

Both elements in fertility, gain, and percentage raised of those born alive have shown considerable decline, while the birth weight and percentage born alive have shown very little decline, according to these figures.

A downward trend can of course be interpreted in two ways. It may be due in some way to the inbreeding, or it may be due in some way to progressively deteriorating environmental conditions. In regard to the latter hypothesis, arguments could be advanced on both sides. There are, however, certain considerations which show that some at least of the decline was genetic in character.

Consider first the inequalities in the decline in different characters. The record for 1914, after eight years of inbreeding, surpassed any preceding year except 1910 in gain, weight at 33 days, and birth weight. The records surpassed five earlier years in percentage born alive, and four earlier years in percentage of the latter which were raised and in total percentage raised. These points indicate that in 1914 environmental conditions were at least as good as in any earlier year, with the probable exception of 1910. Nevertheless the average size and frequency of litters in 1914 is markedly inferior to all years before 1911. Two inbred families had become extinct by 1914, but these two families (1 and 15) were the two lowest in fertility and their elimination should have resulted in genetic improvement of the average. Thus, whatever may have been the case with other characters, the conclusion seems unavoidable that fertility had suffered a real genetic decline after eight years of inbreeding.

A comparison between the inbreds and controls shows that in every respect the controls, born in a given year under identical conditions, were more vigorous than the inbreds. The difference is most marked in the case of size of litter, a result which agrees with the greater decline in size of litter than in other characters. It will be noted that the controls were taken from the same line-bred stock from which the inbred families were mainly derived. The most vigorous guinea pigs were selected in both cases. The inbred families (31 to 39)

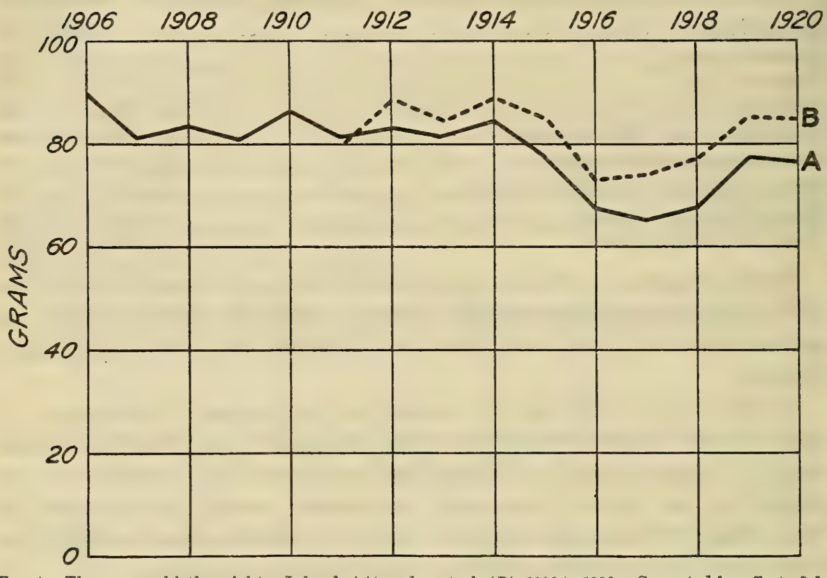

FIG. 4.—The average birth weight. Inbreds (*A*) and controls (*B*), 1906 to 1920. Corrected for effect of size of litter as in Figure 1.

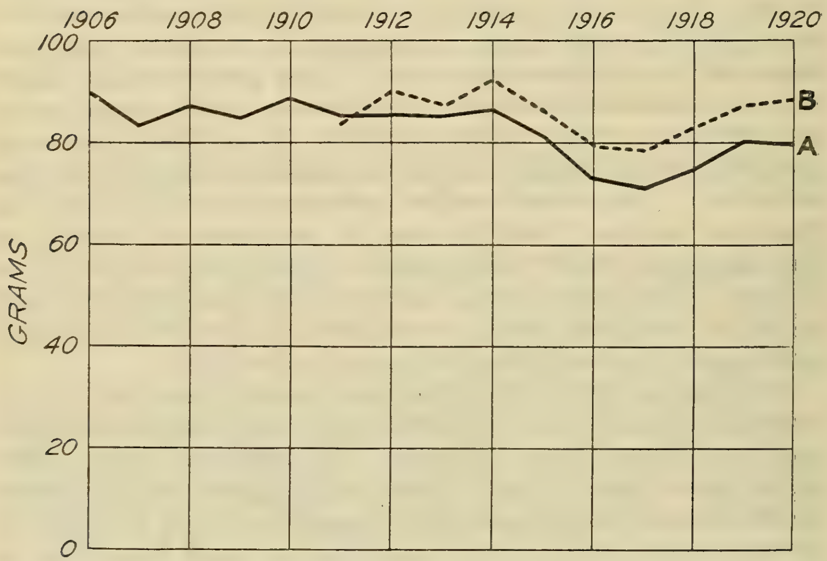

FIG. 5.—The average birth weight of young raised to 33 days. Inbreds (*A*) and controls (*B*), 1906 to 1920. Corrected for effect of size of litter as in Figure 1.

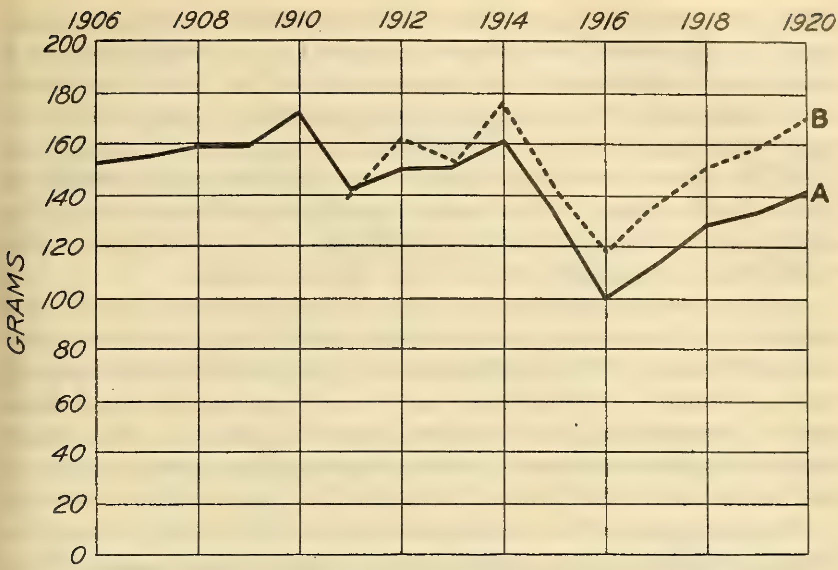

FIG. 6.—The average gain between birth and 33 days. Inbreds (*A*) and controls (*B*), 1906 to 1920. Corrected for effect of size of litter as in Figure 1.

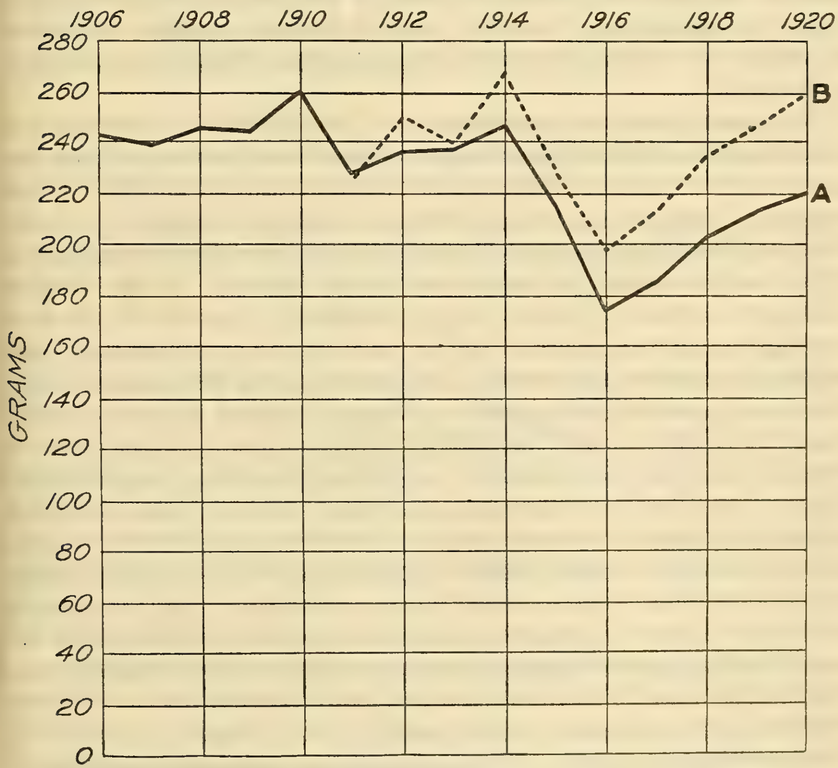

FIG. 7.—The average weight at 33 days. Inbreds (*A*) and controls (*B*), 1906 to 1920. Corrected for effect of size of litter as in Figure 1.

which were derived in part from another source were at least as vigorous as the others, as is shown in Part II. It would thus be a remarkable coincidence if the animals selected to found the control stock happened to have so much more hereditary vigor in every respect than those selected to found the inbred families, especially as it will be shown later that vigor in one character is not correlated with vigor in others. It thus seems improbable to the writer that the differences can be explained on the grounds of an initial genetic inferiority in the foundation stock of the inbred families.

Another possible explanation of the difference between inbreds and controls is in the greater average age at which the latter were mated. During 1916 and 1917 the differences in vigor were even more marked than previously. During these years the average age of inbred dams was 14.1 months and that of control dams 15.5 months. This difference is altogether too small, considering the slight effects of age on the various characters, to give the controls any appreciable advantage.

The average age of the inbreds at their first litter was 5.9 months. About two-thirds of the controls were immature when mated. Their average age was 5.2 months at the first litter. Most of the remaining control matings were between more or less immature guinea pigs. These considerations, therefore, merely indicate another character in which the controls were more vigorous than inbreds, namely, age of maturity.

The most probable interpretation of the differences between the inbreds and controls, is, therefore, that the inbreds started at about the same level of vigor in all respects as the controls, but declined in the course of time as a direct or indirect result of inbreeding. Here, however, the objection arises that the controls have also declined since 1911, and at almost the same rate as the inbreds. If this decline among the inbreds is genetic, so, it would seem, must be the decline among the controls, while if the latter is due to environmental conditions, so must be the former. The decline among the controls, however, was probably not genetic. It may be urged to the contrary that the rigid system of mating by pedigree prevented selection of animals for vigor as effectually as in the inbreeding experiments. This is true, but the characteristics with which we are concerned depend on heredity to such a slight extent that any selection of individuals should be wholly without appreciable effect, one way or the other, in the short time in which the experiment has been in progress. So far as we know at present, there seems to be no valid reason for assuming any genetic change in the control stock. This being the case, the decline since 1911 in both control and inbreds must be environmental. The excellent record made by both stocks in 1919 and 1920 confirms this view. We thus reach the seemingly paradoxical conclusions that the inbreds were falling off genetically from the

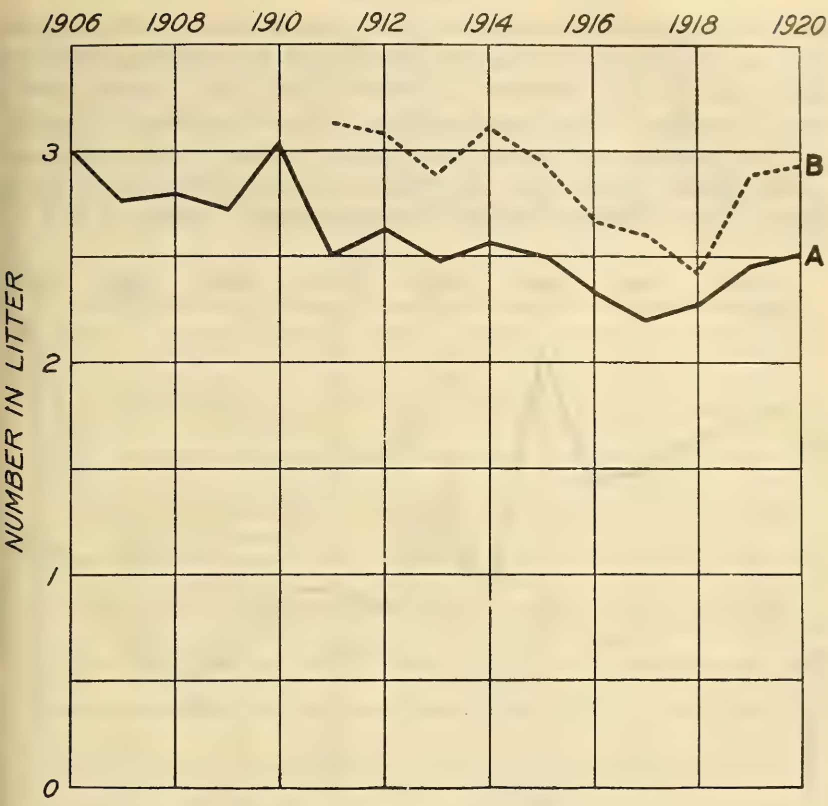

FIG. 8.—The average size of litter. Inbreds (*A*) and controls (*B*), 1906 to 1920.

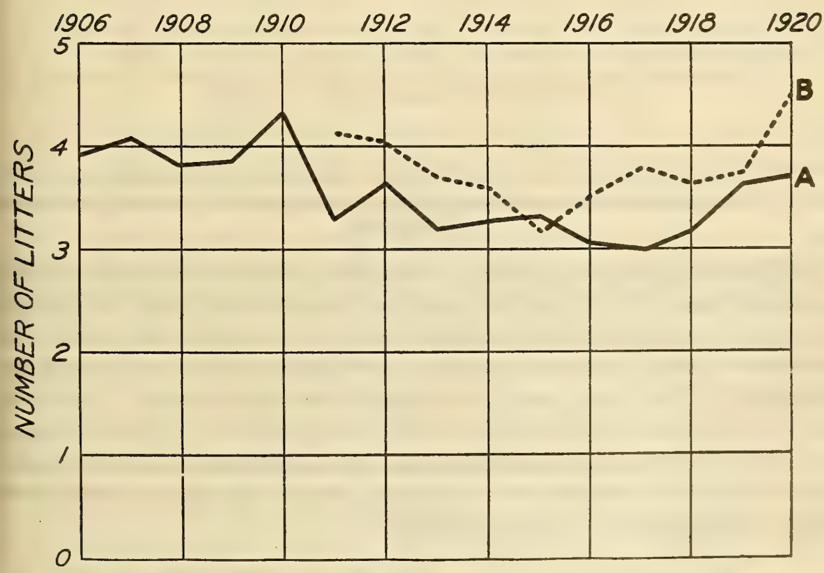

FIG. 9.—The average number of litters produced per year by mature matings. Inbreds (*A*) and controls (*B*), 1906 to 1920.

level of the normally bred stock in the years preceding 1911 in which their records show an actual rise, while they were holding their own genetically in the subsequent years in which their records show a marked decline. The situation brings out most strikingly the difficulty in drawing conclusions from results obtained in different years.

The figures which show the changes in the percentage of young raised in the different sizes of litter separately (Tables 8 and 17)

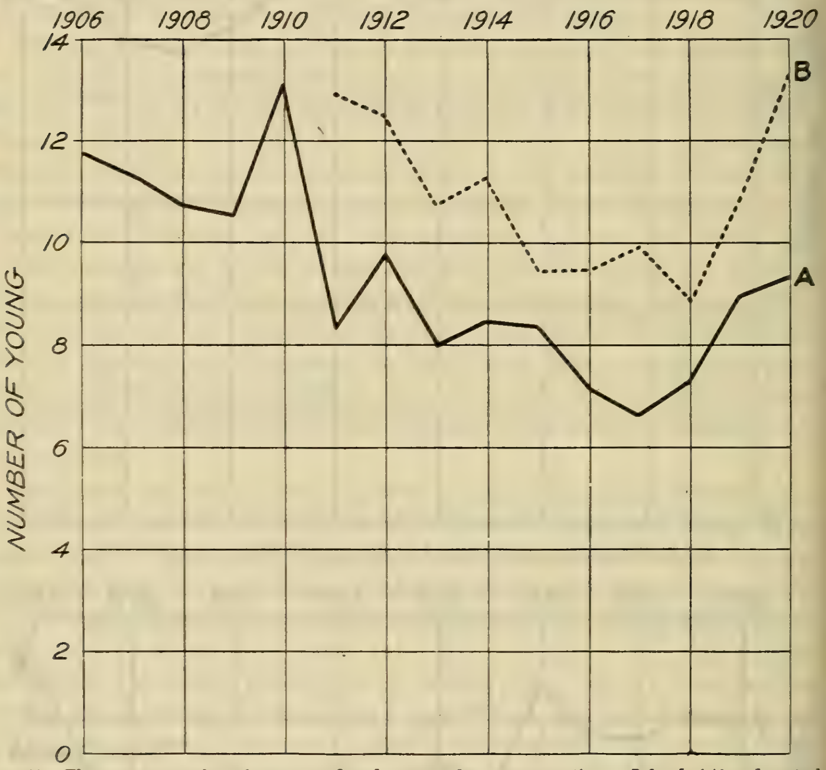

FIG. 10.—The average number of young produced per year by mature matings. Inbreds (*A*) and controls (*B*), 1906 to 1920.

bring out an interesting point, which was touched on earlier in this bulletin (page 15). It will be seen that there was not much difference in the percentages raised in litters of 1 to 5 in the early years. In litters of 1 and 2 there has not been much subsequent decline and the controls do not have much advantage over the inbreds. In litters of 3 the controls begin to show a distinct superiority, which increases in litters of 4 and 5, the decline among the inbreds becoming rapid. Thus it is in the ability to raise large litters that the inbreds show their deterioration most strikingly.

SEX RATIO.

Since the experiment began, there have been no changes in sex ratio which can be relied upon. The number of males per 100 females in different years is given in Table 22. The results are presented graphically in Figure 11. The most interesting point brought out by the figures is the small size of the fluctuations and the absence of any parallelism with those of the other characters. Evidently the favorable conditions of 1910 and 1914 and the unfavorable conditions of 1911, 1916, and 1917 are, like inbreeding itself, without effect on the sex ratio.

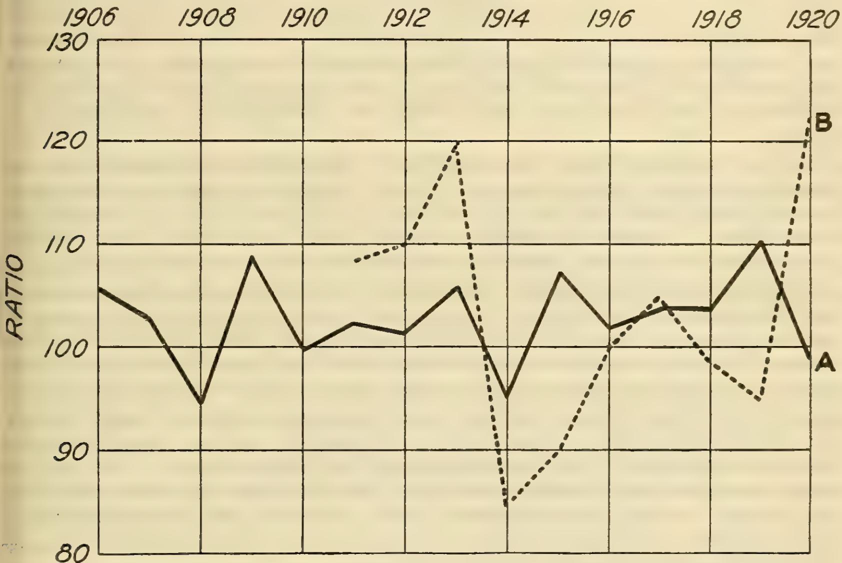

FIG. 11.—Sex ratio. Number of males per 100 females. Inbreds (*A*) and controls (*B*), 1906 to 1920.

TESTS FOR DISEASE RESISTANCE.

Tests were made in 1911 on the resistance of inbred and normal guinea pigs to tuberculosis. The methods used and their results are described, as follows, in a report by Dr. E. H. Riley:

The relative susceptibility to disease of inbred and normally bred guinea pigs was tested by inoculating inbred animals as principals and normally bred animals as checks with an equal quantity of material containing tubercle bacilli. This work was done in cooperation with Dr. E. C. Schroeder, Superintendent of the Bureau of Animal Industry Experiment Station, Bethesda, Md. The inoculations were made under his direction, and facilities were supplied by him for the housing and care of the animals during the progress of the disease. The results of the autopsies, which were made at the Experiment Station, for eight different tests are recorded in Table 5.

The principals used in the first two tests were inbred, brother and sister, for six generations, and were selected from the inbreeding experiment. The checks were not inbred, but were selected from the general stock of guinea pigs bred and reared at the experiment station. Aside from having been born and reared in different buildings, they were raised under practically the same conditions of feeding, care,

and management. At the time they were selected for these two tests there was n apparent difference in principals and checks. All were practically the same ag and weight when they were inoculated. From two to four weeks before inoculatio the animals which were to be inoculated were selected in groups of four, two principa and two checks, all of approximately the same weight, and placed in the cages whic they were to occupy after inoculation. This was done so that they could becom accustomed to being together and to the conditions of care, feed, and managemen which they were to receive after inoculation.

The guinea pigs which were used in the remaining six tests here reported wer the progeny of selected stock, both the seventh generation inbred and the normall bred individuals. They were kept under exactly the same conditions from the tim they were born until they died, so that results obtained from them may be attribute directly to the different methods by which they were bred. When the progen of this selected stock were large enough—which was when they weighed betwee 400 and 500 grams—they were selected according to size and age and placed in pens as indicated in the case of the first two tests, preparatory to inoculation. After inocula tion with tubercle bacilli they were kept in the same cages until they died fror tuberculosis, or for some other cause which was determined so far as possible b autopsy.

Table 5 shows the relative susceptibility to tuberculosis of normally bred an seventh-generation inbred guinea pigs. It will be seen that there were other cause of death than tuberculosis, the most frequent being pneumonia and inflammatio of the bowels. A greater percentage of normally bred than inbred guinea pigs die of generalized tuberculosis. This is accounted for by the fact that a larger percentag of the inbred stock died of other diseases after inoculation, principally pneumonia and inflammation of the bowels. It is probable that their vitality had become di minished to such an extent through inbreeding that they easily succumbed to these diseases. In both tests there were instances where the lesions of tuberculosis wer found on autopsy, but death was due to some other cause. The comparative resist ance to tuberculosis will be apparent on noting the number of days of life after inocula tion with tubercle bacilli. In each of the eight tests the number of days of life afte inoculation was greater in the case of guinea pigs that were not inbred. The shortnes of the time which the animals in some of the tests lived after inoculation was due to the extreme virulence of the organism used. Considering the average number o days of life after inoculation for each test, it will be noted that the inbred guinea pig died 12.49 days sooner than the normally bred pigs.

TABLE 5.—*Relative susceptibility of inbred and normally bred guinea pigs to disease as determined by inoculation with tubercle bacilli.*

Test No.	Normally bred.						Inbred.					
	Cause of death.				Lesions of T. B. present but not cause of death.	Average days of life after injection with tubercle bacilli.	Cause of death.				Lesions of T. B. present but not cause of death.	Average days of life after injection with tubercle bacilli.
	Generalized tuberculosis.	Pneumonia.	Inflammation of bowels.	Other causes.			Generalized tuberculosis.	Pneumonia.	Inflammation of bowels.	Other causes.		
1	99	......	1	1	2	137.2	79	......	4	10	6	116.6
2	65	5	4	2	2	43.6	51	6	11	7	1	42.9
3	12	......	......	......	......	77.2	12	......	......	1	1	74.7
4	21	......	3	......	......	117.0	25	......	2	......	2	108.7
5	20	2	......	......	1	72.4	21	......	1	......	1	48.2
6	15	......	......	......	......	121.3	15	......	......	......	......	104.7
7	8	......	......	......	......	81.8	8	1	......	......	......	68.8
8	20	1	......	......	1	128.5	22	3	......	1	4	117.2
Total	260	8	8	3	6	......	233	10	18	19	15	......
P. ct.	91.23	2.81	2.81	1.05	2.10	......	78.98	3.39	6.10	6.44	5.09	......
Av.	......	......	......	......	......	101.47	......	......	......	......	......	88.98

The results of more recent tests of the resistance to tuberculosis of guinea pigs of the control stock and five of the inbred families have been discussed in a paper by the writer in collaboration with Dr. Paul A. Lewis.[3] In these tests the controls did not live so long on the average as the five inbred families used (2, 13, 32, 35, and 39). These inbred families, however, were markedly differentiated among themselves in resistance and probably do not represent the average of the entire inbred stock as well as did the inbreds of the earlier test, made at a time when most of the families were still on hand.

SUMMARY.

There has been an average decline in vigor in all characteristics during the course of 13 years of inbreeding of guinea pigs, brother with sister. The decline is most marked in the frequency and size of litter, in which it is so great that it would have to be accounted for even though the decline in other respects were assumed to be due wholly to a deterioration in the environmental conditions. The decline is greater in the gains after birth than in the birth weight, and greater in the percentage raised of the young born alive than in the percentage born alive. The ability to raise large litters has fallen off much more than ability to raise small litters.

A comparison of the inbred guinea pigs with a control stock, raised under identical conditions without inbreeding, and derived in the main from the same line-bred stock as the inbred families, indicates that the inbreds have suffered a genetic decline in vigor in all characteristics. The decline in fertility is again shown to be most marked. Experimental inoculation with tuberculosis has shown that the inbreds were inferior on the average to the controls in disease resistance. A study of sex ratio yields results in marked contrast to those obtained in connection with the other characters. There are no significant fluctuations from year to year, no contrast between inbreds and controls, and no indications of change due to inbreeding.

In addition to the points brought out in this bulletin which indicates genetic decline during inbreeding, extensive experiments have been made in which different inbred families have been crossed together. These are described in another paper (Bulletin No. 1121), in which it is shown that crossbred guinea pigs born of unrelated inbred parents are distinctly superior to their inbred relatives in nearly all elements of vigor. A slightly larger percentage are born alive, in small litters at least, and a distinctly larger percentage of those born alive are raised. The young are slightly heavier at birth in a given size of litter and gain much more between birth and wean-

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[3] Wright, S. and Lewis, P. A. 1921. Factors in the resistance of guinea pigs to tuberculosis with especial regard to inbreeding and heredity. Amer. Nat. v. 55, p. 20–50.

ing. They mature earlier, produce larger litters, and produce them more regularly than inbreds. Of the young which they produce a much larger percentage are born alive, especially in large litters, and even more of these are raised than in the first generation. Their young show a further increase in birth weight and in later gains.

Combining the results described in this and in Bulletin No. 1121, there seems no escape from the conclusion that a loss of vigor, especially in fertility, took place as a more or less direct consequence of close inbreeding. The question whether this is an inevitable result of inbreeding, or merely a likely one, as well as other phases of the subject, will be discussed after the presentation of further data.

APPENDIX.

TABLE 6.—*Data on the fertility of the inbred stock by years, 1906 to 1920.*

Year.	Size of litter.								Matings.	Number of litters.	Number of young.	Average size of litter.	Litters per year.	Young per year.
	1	2	3	4	5	6	7	8						
1906	1	4	13	6	......	......	......	......	6.1	24	72	3.00	3.93	11.80
1907	31	77	79	39	13	6	......	......	59.9	245	679	2.77	4.09	11.33
1908	92	173	177	94	46	14	2	......	155.6	598	1,673	2.80	3.84	10.75
1909	138	308	275	153	54	15	2	1	244.3	946	2,573	2.72	3.87	10.53
1910	145	302	410	254	131	26	7	1	293.4	1,276	3,863	3.03	4.35	13.17
1911	184	303	293	120	32	6	2	......	284.7	940	2,359	2.51	3.30	8.29
1912	135	271	276	119	39	11	2	......	231.7	853	2,256	2.64	3.68	9.73
1913	168	274	234	108	27	5	4	......	256.4	820	2,043	2.49	3.20	7.97
1914	132	234	208	105	25	11	......	......	217.2	715	1,835	2.57	3.29	8.45
1915	161	284	288	113	20	6	......	......	260.8	872	2,181	2.50	3.34	8.36
1916	164	300	228	70	18	1	......	......	254.4	781	1,824	2.34	3.07	7.17
1917	103	196	127	32	1	1	......	......	153.5	460	1,015	2.21	3.00	6.61
1918	64	126	89	27	3	......	......	......	96.8	309	706	2.28	3.19	7.29
1919	83	144	136	55	11	2	......	......	118.9	431	1,066	2.47	3.63	8.97
1920	87	208	188	67	16	2	......	......	152.9	568	1,427	2.51	3.71	9.33

TABLE 7.—*The percentage born alive. Inbred stock by years, 1906 to 1920.*

[The average in litters of each size and an index, litters of 1, 2, 3, and 4 weighted 1, 3, 4, and 2, respectively.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1906	100.0	100.0	100.0	100.0	......	......	100.0	1914	81.1	91.2	89.6	82.4	67.2	77.3	87.8
1907	87.1	90.3	91.6	90.4	89.1	61.1	90.5	1915	86.3	90.0	85.2	79.2	64.0	22.2	85.6
1908	85.9	86.1	86.8	84.3	81.7	69.0	86.0	1916	79.9	80.3	73.8	51.1	37.8	100.0	71.8
1909	89.1	89.0	86.7	80.6	79.3	73.3	86.4	1917	83.5	81.4	72.4	60.2	40.0	0.0	73.8
1910	85.5	90.9	91.6	85.2	79.7	71.2	89.5	1918	82.8	85.3	76.0	71.3	46.7	......	78.5
1911	77.2	84.7	86.2	74.6	53.8	63.9	82.5	1919	67.5	88.9	89.0	70.4	50.9	......	83.1
1912	83.7	91.3	86.0	86.6	65.1	51.5	87.5	1920	82.8	89.9	82.8	72.4	77.5	41.7	82.9
1913	80.4	85.9	90.8	78.5	78.5	63.3	85.8								

TABLE 8.—*The percentage raised to 33 days of the young born alive. Inbred stock by years, 1906 to 1920.*

[The average in litters of each size and the index as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1906	100.0	100.0	97.4	75.0	......	......	94.0	1914	85.0	91.3	89.3	79.2	81.0	68.6	87.5
1907	96.3	94.2	92.6	90.8	87.9	90.9	93.1	1915	84.2	87.5	85.2	80.2	56.2	62.5	84.8
1908	89.9	89.6	90.4	89.6	88.3	86.2	90.0	1916	67.2	72.0	60.6	58.0	38.2	0.0	64.2
1909	84.6	84.8	86.7	87.8	89.2	65.2	86.1	1917	80.2	74.6	63.4	57.1	100.0	......	67.2
1910	91.1	93.1	92.6	89.5	82.2	77.5	92.0	1918	86.8	75.8	68.5	61.0	57.1	......	71.0
1911	83.1	86.4	88.0	77.1	80.2	56.5	84.9	1919	89.3	89.4	84.8	69.0	50.0	......	83.5
1912	85.8	86.5	86.6	82.3	66.1	73.5	85.6	1920	80.6	88.0	84.6	74.7	64.5	100.0	83.2
1913	80.0	81.3	75.4	77.3	75.5	57.9	78.0								

TABLE 9.—*The percentage raised to 33 days of all young born. Inbred stock by years, 1906 to 1920.*

[The average in litters of each size and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1906	100.0	100.0	97.4	75.0	......	......	94.0	1914	68.9	83.3	80.0	65.2	54.4	53.0	76.9
1907	83.9	85.1	84.8	82.0	78.5	55.6	84.2	1915	72.7	78.7	72.6	63.5	36.0	13.9	72.6
1908	77.2	77.2	78.5	75.5	72.2	59.5	77.4	1916	53.7	57.8	44.7	29.6	14.4	0.0	46.5
1909	75.4	75.5	75.2	70.8	70.7	47.8	74.4	1917	67.0	60.7	45.9	34.4	40.0	0.0	50.2
1910	77.9	84.6	84.8	76.3	65.5	55.1	82.3	1918	71.9	64.7	52.1	43.5	26.7	......	56.1
1911	64.1	73.1	75.9	57.5	43.1	36.1	70.1	1919	60.2	79.5	75.5	48.6	25.4	......	69.8
1912	71.8	79.0	74.5	71.2	43.1	37.9	74.9	1920	66.7	79.1	70.0	54.1	50.0	41.7	69.2
1913	64.3	69.9	68.4	60.6	59.2	36.7	66.9								

TABLE 10.—*The average birth weight in grams. Inbred stock by years, 1906 to 1920.*

[The average in litters of each size and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1906	104.5	110.7	81.2	67.4	......	......	89.6	1914	106.5	93.0	80.2	69.3	62.3	57.8	84.5
1907	100.3	89.5	77.1	67.6	61.8	54.1	81.2	1915	97.4	87.4	72.9	63.8	53.5	52.8	77.9
1908	107.4	90.1	78.8	72.0	64.4	58.0	83.7	1916	89.9	75.8	63.9	52.7	46.9	......	67.8
1909	102.4	87.6	76.2	68.6	65.8	55.2	80.7	1917	90.8	72.6	60.9	49.6	54.5	......	65.1
1910	110.9	95.5	81.6	72.3	63.8	60.1	86.8	1918	93.1	75.3	63.3	53.4	53.1	......	67.9
1911	102.7	89.8	76.7	67.3	60.4	54.8	81.4	1919	101.8	87.1	73.1	61.0	50.5	39.5	77.8
1912	102.2	92.7	78.6	69.4	61.6	56.4	83.4	1920	102.4	86.0	70.4	62.5	54.5	48.7	76.7
1913	103.8	89.2	78.3	67.1	62.4	50.6	81.9								

TABLE 11.—*The average birth weight in grams of young raised to 33 days. Inbred stock by years, 1906 to 1920.*

[The average in litters of each size and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1906	104.5	110.7	81.1	70.6	......	......	90.2	1914	109.9	94.2	82.0	71.9	67.4	61.6	86.4
1907	101.8	91.8	78.8	69.0	64.3	58.5	83.0	1915	105.3	89.3	76.0	67.1	61.2	60.5	81.1
1908	112.2	92.9	82.2	75.1	67.2	62.9	87.0	1916	99.4	81.5	68.2	59.6	58.3	47.8	73.6
1909	107.5	91.3	80.6	72.6	68.0	58.9	84.9	1917	98.3	77.7	67.0	56.1	59.5	......	71.2
1910	113.0	97.4	83.1	74.2	67.5	63.7	88.6	1918	99.5	81.4	70.3	61.9	79.5	......	74.9
1911	107.4	93.2	79.7	71.9	66.8	58.3	85.0	1919	108.3	87.9	74.7	66.1	60.9	......	80.3
1912	108.1	94.2	81.0	71.7	67.0	64.1	85.8	1920	105.4	87.4	73.5	66.4	60.7	56.5	79.4
1913	109.6	92.4	81.2	70.8	65.9	60.9	85.3								

TABLE 12.—*The average gain in grams between birth and 33 days. Inbred stock by years, 1906 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1906	225.0	161.3	152.6	103.3	......	......	152.6	1914	191.0	174.5	155.6	136.4	124.5	111.3	161.0
1907	185.4	166.7	152.3	130.2	116.2	147.0	155.6	1915	163.5	152.9	126.5	102.3	111.1	137.0	133.3
1908	197.3	165.4	151.9	143.8	127.1	113.8	158.9	1916	143.2	114.7	89.9	77.6	76.7	......	100.2
1909	179.5	170.6	153.5	142.8	140.0	121.8	159.1	1917	141.1	123.8	110.8	94.3	140.0	......	114.4
1910	199.2	186.9	165.4	149.9	134.9	129.5	172.1	1918	139.5	134.3	124.4	121.2	130.0	......	128.2
1911	168.5	157.1	133.0	128.3	121.6	112.7	142.8	1919	164.8	143.6	126.0	115.4	112.9	......	133.0
1912	175.8	166.7	145.5	124.1	125.1	107.0	150.6	1920	163.4	155.9	133.6	124.5	129.3	129.0	141.5
1913	182.1	156.3	148.1	137.2	136.6	165.0	151.8								

TABLE 13.—*The average weight in grams at 33 days. Inbred stock by years, 1906 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1906..	329.5	272.0	233.7	173.9	......	......	242.8	1914..	300.9	268.7	237.6	208.3	191.9	172.9	247.4
1907..	287.2	258.5	231.1	199.2	180.5	205.5	238.6	1915..	268.8	242.2	202.5	169.4	172.3	197.5	214.4
1908..	309.5	258.3	234.1	218.9	194.3	176.7	245.9	1916..	242.6	196.2	158.1	137.2	134.1	......	173.8
1909..	287.0	261.9	234.1	215.4	208.0	180.7	244.0	1917..	239.4	201.5	177.8	150.4	199.5	......	185.6
1910..	312.2	284.3	248.5	224.1	202.4	193.2	260.7	1918..	239.0	215.7	194.7	183.1	209.5	......	203.1
1911..	275.9	250.3	212.7	200.2	188.4	171.0	227.8	1919..	273.1	231.5	200.7	181.5	173.8	......	213.3
1912..	283.9	260.9	226.5	195.8	192.1	171.1	236.4	1920..	268.8	243.3	207.1	190.9	190.0	185.5	220.9
1913..	291.7	248.7	229.3	208.0	202.5	225.9	237.1								

TABLE 14.—*Data on the fertility of the control stock (B) by years, 1911 to 1920.*

Year.	Size of litter.									Matings.	Number of litters.	Number of young.	Average size of litter.	Litters per year.	Young per year.
	1	2	3	4	5	6	7	8	9						
1911..	6	20	41	16	9	2	0	1	0	23.0	95	298	3.14	4.13	12.96
1912..	11	31	35	16	7	6	2	0	1	26.9	109	336	3.08	4.05	12.49
1913..	16	37	66	17	9	5	1	0	0	40.7	151	438	2.90	3.71	10.76
1914..	17	51	55	42	18	8	1	0	0	53.0	192	597	3.11	3.62	11.26
1915..	19	31	40	31	13	2	0	0	0	42.5	136	402	2.96	3.21	9.46
1916..	20	56	64	21	7	2	0	0	0	48.0	170	455	2.68	3.54	9.48
1917..	22	51	59	24	2	0	1	0	0	41.8	159	414	2.60	3.81	9.90
1918..	28	40	43	17	1	1	0	0	0	35.6	130	316	2.43	3.65	8.88
1919..	11	41	46	16	11	4	0	0	0	34.3	129	374	2.90	3.76	10.90
1920..	23	35	50	34	11	4	1	0	0	34.7	158	465	2.94	4.55	13.44

TABLE 15.—*The percentage born alive. Control stock by years, 1911 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1911..	100.0	87.5	81.3	87.5	86.7	91.7	86.3	1916..	90.0	92.0	88.5	73.8	80.0	16.7	86.8
1912..	81.8	90.3	92.4	96.9	91.4	77.8	91.6	1917..	72.7	91.2	84.2	84.4	90.0	......	85.2
1913..	87.5	87.8	92.9	86.8	88.9	63.3	89.6	1918..	85.7	87.5	79.8	79.4	40.0	......	82.6
1914..	82.3	86.3	93.3	86.9	85.6	81.2	88.8	1919..	90.9	92.7	87.7	87.5	83.6	83.3	89.5
1915..	73.7	87.1	92.5	92.8	84.6	50.0	89.1	1920..	78.3	88.6	84.7	81.6	85.4	70.8	84.6

TABLE 16.—*The percentage raised to 33 days of the young born alive. Control stock by years, 1911 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1911..	66.7	91.4	92.0	75.0	87.2	72.7	85.9	1916..	83.3	86.4	82.4	77.4	42.9	100.0	82.7
1912..	88.9	92.8	89.7	83.9	100.0	82.2	89.4	1917..	87.5	86.0	78.5	75.3	77.8	......	81.0
1913..	85.7	81.5	85.3	57.6	75.0	68.4	78.7	1918..	87.5	84.3	84.5	85.2	......	......	84.9
1914..	85.7	94.3	90.9	84.2	93.5	79.5	90.0	1919..	70.0	88.2	86.8	83.9	82.6	45.0	85.0
1915..	64.3	87.0	89.2	88.7	78.2	66.7	86.0	1920..	88.9	93.5	91.3	80.2	66.0	52.9	89.5

TABLE 17.—*The percentage raised to 33 days of all young born. Control stock by years, 1911 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1911..	66.7	80.0	74.8	65.6	75.6	66.7	73.7	1916..	75.0	79.5	72.9	57.1	34.3	16.7	71.8
1912..	72.7	83.9	82.9	81.2	91.4	63.9	81.9	1917..	63.6	78.4	66.1	63.5	70.0	......	69.0
1913..	75.0	71.6	79.3	50.0	66.7	43.3	70.5	1918..	75.0	73.7	67.4	67.6	0.0	......	70.1
1914..	70.6	81.4	84.8	73.2	80.0	64.6	79.9	1919..	63.6	81.7	76.1	73.4	69.1	37.5	76.0
1915..	47.4	75.8	82.5	82.2	66.2	33.3	76.6	1920..	69.6	82.9	77.3	65.4	56.4	37.5	75.8

TABLE 18.—*The average birth weight in grams. Control stock by years, 1911 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1911..	92.8	89.8	77.1	64.8	64.3	57.8	80.0	1916..	89.2	85.0	70.1	56.8	48.6	50.3	73.8
1912..	115.4	94.8	85.9	72.9	67.0	60.0	88.9	1917..	99.5	83.4	69.5	57.8	62.5	......	74.3
1913..	110.2	90.6	81.1	70.2	60.5	53.5	84.7	1918..	109.5	85.6	68.2	65.8	48.3	47.8	77.1
1914..	105.1	101.1	83.6	73.6	69.3	58.9	89.0	1919..	105.4	95.3	80.5	69.5	62.2	58.7	85.2
1915..	98.2	94.2	83.4	68.7	61.3	47.0	85.2	1920..	118.0	90.4	80.8	69.2	59.2	45.8	85.1

TABLE 19.—*The average birth weight in grams of young raised to 33 days. Control stock by years, 1911 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1911..	99.5	93.6	80.2	69.3	65.1	62.0	84.0	1916..	108.5	88.7	73.1	64.5	53.7	59.5	79.6
1912..	110.7	96.2	88.5	73.7	67.9	63.6	90.1	1917..	105.2	86.8	73.0	63.5	64.5	......	78.5
1913..	111.2	96.6	83.0	70.1	64.2	63.0	87.3	1918..	117.4	91.3	73.8	71.9	......	......	83.0
1914..	117.8	103.7	85.5	77.8	72.7	63.2	92.7	1919..	113.1	97.9	80.9	72.2	65.6	60.1	87.5
1915..	100.1	95.1	84.5	69.8	64.5	59.5	86.3	1920..	118.9	95.9	83.4	72.1	63.2	51.2	88.4

TABLE 20.—*The average gain between birth and 33 days, in grams. Control stock by years, 1911 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1911..	195.0	141.5	136.7	127.8	92.6	120.0	142.2	1916..	173.0	137.2	102.0	96.6	102.5	130.0	118.6
1912..	168.8	178.3	164.4	120.4	139.7	112.9	160.2	1917..	170.0	152.7	129.8	98.1	90.7	......	134.3
1913..	190.0	175.5	135.9	128.8	109.3	103.4	151.8	1918..	193.0	168.7	135.0	139.8	......	......	151.9
1914..	198.4	201.5	167.9	143.2	114.0	130.8	176.0	1919..	185.0	180.6	147.8	133.5	112.8	113.8	158.5
1915..	160.5	171.0	131.1	114.4	94.8	95.0	142.7	1920..	218.1	182.2	161.3	147.1	123.7	120.5	170.4

TABLE 21.—*The average weight at 33 days, in grams. Control stock by years, 1911 to 1920.*

[The average in each size of litter and the index, as in Table 7.]

Year.	Size of litter.						Index.	Year.	Size of litter.						Index.
	1	2	3	4	5	6			1	2	3	4	5	6	
1911..	294.5	235.1	216.9	197.1	157.7	182.0	226.2	1916..	281.5	225.9	175.1	161.1	156.2	189.5	198.2
1912..	279.5	274.5	252.9	194.1	207.6	176.5	250.3	1917..	275.2	239.5	202.8	161.6	155.2	......	212.8
1913..	301.2	272.1	218.9	198.9	173.5	166.4	239.1	1918..	310.4	260.0	208.8	211.7	......	......	234.9
1914..	316.2	305.2	253.4	221.0	186.7	194.0	268.7	1919..	298.1	278.5	228.7	205.7	178.4	173.9	246.0
1915..	260.6	266.1	215.6	184.2	159.3	154.5	229.0	1920..	337.0	278.1	244.7	219.2	186.9	171.7	258.9

TABLE 22.—*The number of males and females and the sex ratio (males per 100 females).*

[Inbred and control stocks by years, 1906 to 1920.]

Year.	Inbred stock.			Control stock.			Year.	Inbred stock.			Control stock.		
	Males.	Females.	Males per 100 females.	Males.	Females.	Males per 100 females.		Males.	Females.	Males per 100 females.	Males.	Females.	Males per 100 females.
1906........	37	35	105.7	......	......	......	1015........	1,129	1,051	107.4	191	211	90.5
1907........	343	333	103.0	......	......	......	1916........	894	879	101.7	223	223	100.0
1908........	806	855	94.3	......	......	......	1917........	498	480	103.8	209	199	105.0
1909........	1,335	1,223	109.2	......	......	......	1918........	341	329	103.6	151	153	98.7
1910........	1,919	1,922	99.8	......	......	......	1919........	556	504	110.3	178	187	95.2
1911........	1,188	1,158	102.6	155	143	108.5	1920........	704	711	99.0	255	209	122.0
1912........	1,135	1,119	101.4	176	160	110.0							
1913........	1,051	991	106.0	239	199	120.1	Total....	12,831	12,529	102.4	2,051	2,007	102.2
1914........	895	939	95.3	274	323	84.8							

II. DIFFERENTIATION AMONG INBRED FAMILIES.

The first part of this bulletin gives a description of an inbreeding experiment with guinea pigs begun in 1906 by the Bureau of Animal Industry. An account is given of the origin of 23 families, descended from 23 females and 9 males by matings exclusively of brother with sister. It is shown that the inbred stock as a whole suffered a decline in vigor in all characteristics studied, but most markedly in fertility. This decline was not, however, a rapid one, the relatively high vigor after more than a dozen generations of the closest inbreeding being, perhaps, as noteworthy a result as the fact of a slow average decline. In this part of the bulletin the different families will be considered separately, in order to determine how far differentiation has taken place among them and how far inbreeding has affected them alike.

DIFFERENTIATION IN COLOR.

A differentiation among the families in color has been obvious. The original stock contained both intense and dilute agoutis, blacks with red, yellow or cream spotting, reds, and albinos. All grades of the piebald and tortoise-shell patterns were found. Each of the families produced a variety of colors in the early generations. As time went on, however, different colors automatically became fixed in different lines, and as the families became more homogeneous through the elimination of early branches from the main line of descent most of them came to be characterized by a particular color. The mode of inheritance of the main color varieties is thoroughly understood, and as their automatic fixation through inbreeding is a well-known consequence of their mode of inheritance, it will not be necessary to go into the rather complex details.

Of greater interest is the fixation of those color variations and patterns whose heredity has not yet been analyzed as Mendelian and which appear to follow a blending mode of inheritance. Among these characters are the minor variations in intensity of color, and the minor variations in the extent and localization of the piebald and tortoise-shell patterns. Among the minor differences in intensity come interesting contrasts between Families 38 and 32 and between Families 18 and 35. All four of these families have red or yellow spotting. The red in Family 32 is always a remarkably intense mahogany color, like that of no other guinea pigs which the writer has seen. Family 38 has pale red or yellow, impossible to confound with the red of Family 32, but rather similar to the pale red or yellow of Family 18. The young of Family 18 are usually classified as light red when born, appearing slightly more intense than the young in Family 38, but changing to a typical yellow when older. Family 35 shows a typical yellow at all ages. When these 4 families are crossed

with albinos (c^ac^a), it at once becomes apparent that Families 32 and 38 alike have the intensity factor (C), the crossbred young (Cc^a) showing a red spotting which is less intense than that of Family 32 but more intense than in Family 38. Families 18 and 35, on the other hand, are proved unmistakably to possess an intermediate factor in the albino series (c^k) the young in both cases having the cream-colored spots typical of heterozygous dilutes (c^kc^a).

In quantity of white spotting, the families have also become markedly differentiated from each other. At one extreme are Families 38 and 39 with only about 20 per cent white on the average, and at the other are Families 13 and 31, with about 90 per cent of white. The remaining families are scattered between these limits. Similarly, grades of yellow spotting have also become fixed. This subject will be treated in detail in another paper. Here it is enough to note that the 23 families, most of them descended from the same line-bred stock and the rest of them half descended from it, have automatically become so differentiated from each other in kind of color, in intensity of color, and in pattern that a new litter could usually be recognized at a glance as belonging to its particular family.

ABNORMALITIES.

Another kind of variation in which differentiation among the families is clearly shown is polydactylism. Guinea pigs normally have only three toes on the hind feet. It is not uncommon, however, to find a vestigial fourth toe hanging loosely beside the others. Castle[4] has shown that this condition is hereditary although not following any simple Mendelian scheme. He produced by selection a stock in which the fourth toe was regularly as well developed as the other toes. This abnormal fourth toe, it may be noted in passing, is interesting from an evolutionary standpoint as a true vestigial organ, representing a toe which is present in most rodents but which cavies have nearly lost. It is of a different kind from the extra toes occasionally found in cats and man, which are due to a symmetrical reduplication. The extra toe of guinea pigs is not placed symmetrically with respect to any of the other toes.

Extra toes were occasionally to be found in the stock from which the inbreeding experiments were started. Four cases were recorded in the control stock (B) between 1911 and 1915. Among the inbred families, 1906 to 1915, the distribution of extra toes has been irregular. There were 181 cases recorded in Family 35, 152 in Family 31, 59 in Family 38, 26 in Family 36, 25 in Family 11, and 19 in Family 24, while 12 were scattered among Families 2, 7, 14, 17, and 39. None were recorded in Families 1, 3, 13, 15, 18, 19, 20, 21, 23, 32, and 34.

[4] Castle, W. E. 1906. The origin of a polydactylous race of guinea pigs. Carnegie Inst. Wash. Pub. No. 49.

The genetic differentiation among the families is obvious. It is further interesting to note that there was segregation in this respect among the lines of descent within the families.

The history of Family 31 is especially interesting. The original pair were both normal as to toes and produced only normal young. Two matings were made in the next generation, neither of which produced any four-toed young. Sixty-six matings were made among the descendants of one of them. Among the numerous young only 2 are recorded as four-toed. One of these came in the fourth generation, the other in the twelfth. The two matings which produced the four-toed young also produced 11 normal young. Evidently the vestigial toe was almost below the threshold of appearance in this line. A mating of 2 normals derived from the other mating in the first generation produced 11 normals but also 4 four-toed young. Two matings made in the next generation left numerous descendants. The two lines derived from these two matings and thus diverging in the third generation were remarkably different from each other in respect to heredity of polydactylism. One line starting from a mating of normal with normal contained 18 matings, of which only 5 produced four-toed young. These 5 matings produced 23 normal young and 6 four-toed young. The other line, starting from a mating of 2 four-toed animals, contained 27 matings, of which 25 produced 139 four-toed to 70 normal young. A large percentage of the four-toed young in this line had four well-developed toes on both hind feet.

There are similar evidences of segregation within Family 35. In this case three out of four lines starting from matings in the second generation produced numerous four-toed young. The other line, containing 43 matings, produced none. The segregation among the family lines is so sharp that it is probable that a careful investigation of polydactylism would yield Mendelian results, though much non-genetic variation must be present. The differentiation among the families and among the lines of descent within families is obviously very similar to that found in the case of the color characters.

Of more interest from the standpoint of inbreeding are abnormalities which are not merely reappearances of formerly normal characters. It has often been held that inbreeding has a specific tendency to cause physical malformations to appear. The array of bottles of preserved specimens of abnormalities which have appeared in the present experiments is indeed rather imposing. The total number of young born, however, has been so great that the sum of all of the abnormalities (excluding polydactylism) forms really an insignificant proportion.

Most of the types of abnormalities have appeared also in the control stock, showing that inbreeding can not be the prime cause of their appearance. Moreover, a study of their distribution among the fami-

lies shows a situation similar to that found with color, pattern, and polydactylism.

Three of the families (1, 9, and 20) produced no abnormalities of any kind. It will be shown later that Family 1 was one of the two poorest families in regard to vigor. It was the second family to become extinct, doubtless because of its deterioration in both fertility and ability to raise such young as were born. The other poorest family, No. 15, produced only two abnormalities. One was no more serious than a tuft of long hair or "mustache" on the right side of the muzzle. The other was an animal in which the legs were rudimentary.

Turning to the family which was unquestionably the most vigorous between 1906 and 1915, namely, Family 13, we find a considerable number of abnormalities. Aside from 7 animals with "mustaches," 1 with an abnormally small left eye, 1 with the neck twisted to the right, 1 with a hole in the skull through which the brain protruded, and one with the front legs bent back against the body, there were 11 of the well-known cyclopean type of monster. Another cyclops was a crossbred, three-fourths of whose ancestry came from Family 13. All of the other inbred families combined produced only 23 of these monsters. Five came from Family 19, 9 from Family 32, 3 from Family 35, and the rest from Families 7, 11, 17, and 18. Here again we find evidences of family differentiation, the family most productive in cyclopean monsters happening to be the most vigorous in other respects.

The distribution of the cyclopeans within Family 13 is interesting. All were descended from a single mating in the second generation. All but two (uncle and niece) were descended from a single mating in the seventh generation. Two were sisters.

As the 11 cyclopeans in Family 13 had 162 normal brothers and sisters, the variation can not be a simple Mendelian recessive. Nevertheless it seems clear that a tendency to produce it is hereditary, segregating out in particular lines of particular families, and that this tendency has nothing to do with the vigor of the stock. One cyclopean monster of an extreme type was produced by the control stock.

In another type of monster the body was undersized (which was not the case in the cyclopean monsters) and the legs were rudimentary. In extreme cases a leg would be represented externally merely by a single claw to be found only by feeling in the fur. One such case, as already noted, was produced by Family 15. There were 5 in Family 24 and possibly 1 in Family 39. Two of those in Family 24 were born in different litters from a single mating in the eighth generation. This mating also produced 16 normal young. Three matings were made among the normal young. Two produced only normals

(6 and 24, respectively). The other produced the 3 other abnormals as well as 10 normals. These abnormals again all came in different litters. Each of the five litters containing an abnormal also contained normals. Only one mating was made in the next generation from this line, and only 3 normal young were produced. The abnormality is evidently hereditary and the data consistent with the view that it is due to a recessive Mendelian factor. The matings of normal to normal produced 26 normals to 5 abnormals. It is quite probable that the abnormality arose as a mutation sometime during the course of the experiment, as it is hardly likely that it would have failed to appear in others of the many lines in this family if the factor had been present in the original pair. Even in this case, however, it is clear that we are dealing with a definite hereditary factor or factors, not with a specific effect of inbreeding.

The same conclusion applies to another abnormality, the absence of one or both eyeballs. There were 4 of these animals in the control experiment and 11 among the inbreds. Eight were produced by Family 38, 2 by Family 7, and 1 by Family 32. Five individuals, one in each of the Families 3, 11, 13, 31, and 36, were recorded as having one eye smaller than the other.

The remaining abnormalities were well scattered among the families. There were nine with various malformations of the jaws or muzzle. One described as having a "bulldog face with no upper incisors" appeared among the controls. There were 23 with deformed legs of various kinds besides those with miniature legs, noted above. Three of this kind appeared among the controls. Ten were described as having a hole in the skull, through which the brain protruded. Three had abnormally large heads. There were 2 in which toes were fused, a variation which also appeared among the controls. Twenty-nine individuals had "mustaches," besides 2 among the controls. The inheritance of many of these variations is, is, of course, very doubtful.

The general conclusion which is suggested by a survey of these abnormalities is the same as that advanced in connection with color, pattern, and vestigial toes. Inbreeding per se has nothing to do with their origin. We find a cyclops, several eyeless pigs, and several head and leg abnormalities among the controls. Whether an abnormality appears in an inbred family depends mainly on its initial heredity in that particular respect. One family, as it happens the most vigorous, has the greatest tendency toward producing cyclopean monsters. Another family produces most of the eyeless animals. Another produces monsters with miniature legs. The two weakest families, in most respects, produce few or no abnormalities. Thus inbreeding can not be considered to be a cause of the origin of abnor-

malities. At the most it merely brings out more frequently variations which depend on recessive factors, which factors are either already in the stock or which arise from time to time as mutations.

DIFFERENTIATION IN VIGOR.

These results raise the question as to whether the inbred families have become differentiated in a similar manner in the less tangible traits connected with vigor, such as fertility, rate of growth, and ability to raise the young successfully.

The characters of this kind which have been used in the present work were defined in the first part of this bulletin. Their relations to each other and their variation under the influence of external conditions were discussed there at some length. Under the heading of fertility are considered the average size of litter, the number of litters produced per year by mature parents, and the product of these factors, the number of young produced per year. The rate of growth is studied in the birth weight, in the gain between birth and weaning at 33 days of age, and in the sum of these weights, the weight at 33 days. The percentage of the young born alive, the percentage of these raised to weaning, and the product, the percentage of all of the young raised to weaning, measure the vitality of the young and the capacity of the females for raising them.

Averages for each of these characters have been calculated in each inbred family for two periods, 1906 to 1910, and 1911 to 1915. In the former period most of the families were composed of several lines of descent, connected with each other only in the first generation of inbreeding. Many of the lines had been eliminated before the second period, in which, therefore, the families might be expected to be more homogeneous. The figures on mortality among the young and also the weights were calculated separately for each size of litter. Indexes were obtained, as previously, by weighting the averages for litters of 1, 2, 3, and 4, in the ratio 1:3:4:2. The results are given in Tables 7 to 15.

Examination of the tables reveals considerable differences between the families. Table 1 shows the extremes in the period from 1911 to 1915.

TABLE 1.—*Families with extreme records in the period from 1911 to 1915.*

Character.	Best family.	Poorest family.
Size of litter	No. 11 (2.90)	No. 1 (1.74).
Litters per year	No. 23 (3.80)	No. 38 (2.46).
Young per year	No. 35 (10.34)	No. 1 (4.68).
Percentage born alive	No. 39 (91.5 per cent)	No. 3 (76.5 per cent).
Percentage raised of those born alive	No. 2 (89.3 per cent)	No. 3 (76.1 per cent).
Percentage raised	No. 20 (78.5 per cent)	No. 3 (57.7 per cent).
Birth weight of young raised	No. 13 (91.5 grams)	No. 2 (75.6 grams).
Gain from birth to 33 days	No. 11 (169.1 grams)	No. 2 (122.2 grams).
Weight at 33 days	No. 11 (260.2 grams)	No. 2 (197.8 grams).

A certain amount of difference between families from 1911 to 1915 would be expected to occur simply by chance, owing to the limited number of observations. It is important to determine whether the actual differences are greater than those expected by chance. The actual differences can best be measured by considering the families as units and finding the standard deviation in the group of family means, with respect to each character. The reliability of each family mean can be estimated by calculating its standard deviation (σ_m). The average of these standard deviations gives the standard deviation in the group of family means which might be expected by chance, and may be compared with the figures actually found.

The expected standard deviation in each family in the cases of the percentage born alive, the percentage raised of those born alive, and the total percentage raised, can be calculated by the formula $\sigma_{100\,p} = 100\sqrt{\frac{p(1-p)}{n}}$ where 100 p is the percentage in question and n is the number of cases. In the case of the size of litter, the formula for the standard deviation of the mean is $\frac{\sigma}{\sqrt{n}}$ where σ is the standard deviation within a family (about 1.14) and n is the number of litters. In the cases of the weights the same formula applies, but the use of indexes somewhat complicates the matter. The indexes for the standard deviations of the weight at birth of the young raised to 33 days, the gain, and the weight at 33 days are approximately 11.0, 34.0, and 39.4 grams. These figures were derived from the total inbred families in 1916 and 1917. The figures within a single family would be slightly smaller, but these results are sufficiently accurate for the present purpose. For the reasons given in the discussion of the indexes in Part I of this bulletin this should be a compromise between the number of litters of 1 to 4 and the number of individuals in these litters. A standard deviation of means based on litters is about 60 per cent larger than one based on individuals. A reduction of 23 per cent from the figure based on a number of litters is in accordance with the assumptions involved in the indexes and is used here. In the cases of the number of litters and number of young produced per year the writer has not attempted to calculate the standard deviation to be expected by chance, and the reality of the differentiation among the families must be established by other means.

Having found the standard deviation of the mean in each family, the unweighted average in the 22 families has been used to measure the standard deviation to be expected by chance in the population of family means. Table 2 gives the comparison of these expected figures with the standard deviations actually found. It will be seen that in every case the actual variation is much the greater. The

difference is greatest among the weights, but is great enough in the other cases to make it reasonably certain that there are significant differences among the families, differences which might be expected to persist, even though so many young were raised in each family that the standard deviation of each family mean became practically zero.

TABLE 2.—*The differentiation among the inbred families.*

[The mean and standard deviation of the 22 family means relative to each of the characteristics studied is given for the two periods 1906 to 1910 and 1911 to 1915 (columns 2, 3, 5, and 6). The standard deviation of family means expected from random sampling (columns 4 and 7) may be compared with the actual standard deviations (columns 3 and 6). The yearly rate of decline in each element of vigor is estimated taking either the family (column 8) or the individual (column 9) as the unit.]

Character.	1906–1910.			1911–1915.			Yearly decline.	
	Mean of family means.	σ of means.		Mean of family means.	σ of means.		Family the unit.	Individual the unit.
		Actual.	Due to chance.		Actual.	Due to chance.		
Size of litter	2.820	0.235	0.116	2.492	0.268	0.094	0.085	0.04[illegible]
Litters per year	4.090	.321	....	3.303	.383	....	.203	.11[illegible]
Young per year	11.536	1.302	....	8.227	1.226	....	.853	.45[illegible]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Percentage born alive	88.55	3.92	2.50	85.00	3.99	2.03	0.92	0.29
Percentage raised of those born alive	89.36	3.80	2.42	82.95	4.24	1.96	1.65	1.04
Percentage raised	79.14	4.96	3.20	70.64	5.38	2.59	2.19	1.16
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Birth weight of all young	83.95	3.88	....	81.82	4.19	....	0.55	0.19
Birth weight of young raised	86.86	3.57	0.87	85.00	4.57	0.70	.48	1.19
Gain to 33 days	165.18	9.26	2.67	146.55	11.75	2.16	4.80	1.96
Weight at 33 days	252.04	12.17	3.10	231.55	15.02	2.51	5.28	2.15

It will be noticed that, with one exception, the actual variation among family means is greater in the second period than in the first, in spite of the fact that the larger numbers born in the second period have reduced the variation due to random sampling. In the case of the one apparent exception, the number of young produced per year, the standard deviation is slightly smaller in the second period, but the coefficient of variation is much greater, owing to the smaller mean. It can thus be said with safety that there has been a pronounced increase in the differentiation among the families in every respect between the first and second periods. This increase in differentiation is a natural consequence of the increasing homogeneity in each family.

The unweighted average of the family means was calculated for each character in each period, and a consideration of the results brings out some interesting points. In every case the second period shows a marked decline compared with the first. This is in harmony with the results described in Part I. It is to be noted, however, that in the present figures the family is the unit, so that changes in relative importance among the families have no effect on the results. In order to make a comparison with the results obtained when all families were combined we must calculate the average difference

in time between the two periods. The average date of birth for the first period comes out 1909.04 or 1909.07, depending on whether the years are weighted by the number of litters born or the number of individuals. The average for the second period is 1912.93 in both cases. The periods may thus be considered as 3.88 years apart on the average. The yearly rate of decline in each character on this basis is given in the next to the last column of Table 2. The last column gives the rate of decline found, as described in Part I, by fitting the best straight line to the yearly averages for all inbred young born between 1907 and 1915. It appears that the decline within an average family has been about twice as rapid as that in the inbred stock as a whole. The reason is easy to understand. The vigorous families expanded at the expense of the families in which hereditary weaknesses had become fixed, and this expansion to some extent obscured the decline within the families.

DETAILED STUDY OF FAMILY CHARACTERS.

The existence of a significant degree of differentiation among the families would lead us to expect a correlation between the average of a character in the first period and its average in the second. Inspection of Tables 7 to 15 in fact soon shows that families which were high in rank in one period tended to be above the average in the other, and conversely. Among the extreme families listed in Table 1, Family 1 produced the smallest litters from 1906 to 1910 as well as from 1911 to 1915. Family 3 had the smallest percentage born alive in both periods excepting Family 15, which became extinct in 1911, while Family 13 led in birth weight in both periods, and Family 2 made the poorest gains.

More conclusive evidence can be obtained by calculating the coefficients of correlation between the averages in the two periods. This has been done for each character, using the product-moment method (Table 3). It will be seen that all of the correlations are positive and the lowest is +0.25. Unfortunately, the probable errors are also rather high, owing to the small number of families (22) on which the correlations are based. Nevertheless, a pronounced and lasting differentiation among the families is demonstrated in most of the cases. In regard to rate of growth, we find correlations of +0.65, +0.64, and +0.68 for birth weight, gain, and weight at 33 days, respectively, with a probable error of only ±0.08 in each case. The permanent differentiation in size of litter is of similar degree, with a correlation of +0.65 ±0.08 between the periods. In regard to the other element in fertility, the frequency of litters, the correlation of +0.25 ±0.13 can merely be said to be consistent with a genetic differentiation. Total fertility, as measured by the number

of young produced per year by mature matings, shows a probably significant correlation of +0.41 ±0.12. Hereditary differences in the ability to bear the young alive are demonstrated by the correlation of +0.51 ±0.11, while hereditary differences in the percentage raised of the young born alive are at least indicated by the correlation of +0.32 ±0.13. The correlation in the case of percentage raised of all the young is of course a compromise between these figures, +0.36 ±0.13.

In considering these results it must be carefully noted that a significant degree of genetic differentiation among the families during a given period of time does not necessarily imply a significant degree of correlation between different periods. It is to be expected that there will be a certain amount of differentiation among the lines of descent, which diverged in the early generations within a family. The lines of descent which are most important in the first period are not always most important in the second. A striking example of a change in the character of a family, No. 35, brought about by the rapid displacement of one set of lines of descent by the expansion of a hitherto insignificant line, is discussed later. If this family and another one, Family 2, which also changed its character to a very marked extent in the course of the experiment, were omitted from the tables, the correlations would be increased.

TABLE 3.—*Correlations between the family averages for each character, 1906 to 1910, and those for the same character 1911 to 1915.*

[The positive correlations indicate heredity. Based on 22 families.]

Vitality:	
Per cent born alive	+0.51
Per cent raised of those born alive	+.32
Per cent raised	+.36
Growth:	
Birth weight	+.65
Gain	+.64
33-day weight	+.68
Fertility:	
Size of litter	+.65
Litters per year	+.25
Young per year	+.41

TABLE 4.—*Correlation between the family averages for various pairs of characters. Calculated separately for 1906 to 1910 and 1911 to 1915.*

[Significant correlations indicate physiological interrelation. Effect of size of litter on mortality and growth eliminated from consideration by use of indexes.]

		1906–10.	1911–15.
Vitality	Per cent born alive with per cent raised (BA)[1]	+0.03	+0.30
Growth	Birth weight with gain	+ .75	+ .59
Fertility	Size of litter with litters per year	+ .04	− .03
Vitality with growth	Per cent born alive with birth weight	− .08	+ .01
	Per cent born alive with gain	+ .03	− .28
	Per cent raised (BA)[1] with birth weight	+ .07	− .21
	Per cent raised (BA)[1] with gain	+ .02	− .23
	Per cent raised with 33 days' weight	− .04	− .31
Vitality with fertility	Per cent born alive with size of litter	− .10	+ .12
	Per cent born alive with litters per year	+ .04	+ .01
	Per cent raised (BA)[1] with size of litter	+ .28	+ .17
	Per cent raised (BA)[1] with litters per year	.00	+ .23
	Per cent raised with young per year	+ .03	+ .29
Fertility with growth	Size of litter with birth weight	+ .26	+ .62
	Size of litter with gain	+ .37	+ .62
	Litters per year with birth weight	− .05	− .34
	Litters per year with gain	+ .09	− .22
	Young per year with 33 days' weight	+ .21	+ .22

[1] Per cent raised of those born alive.

The demonstration of significant differences among the families in rate of growth, fertility, and mortality among the young, raises the question as to whether the variations in these characters are inherited independently of each other, or are merely so many manifestations of a differentiation in general vigor. Such a differentiation, if present, might be due to the transmission of disease in families as well as to genetic causes. To settle this point, the various characters were correlated with each other in each period, again using the product-moment method. The results are given in Table 4.

Before examining these results in detail it will be well to point out that if the differentiation among the families were merely in general vigor we should expect to find even higher correlations than where the families were compared at different periods of time with respect to a given character. In the present case we are comparing characters of the very same animals.

The results, however, contain few correlations which are at all significant, remembering that only values above 0.40 can be looked on as definitely significant, while values below 0.30 can be given little weight. Among the 36 correlations, only 4 are above +0.40, and only 2 more are between +0.30 and +0.40. The latter are balanced by two correlations between −0.30 and −0.40. This, of course, is directly antagonistic to the hypothesis of a differentiation in general vigor, genetic or otherwise.

Two of the four significant correlations are between birth weight and gain—namely, +0.75 ±0.06, and +0.59 ±0.09 in the two

periods. There are evidently genetic factors which act alike on the rate of growth before and after birth. It would, indeed, be surprising if it were otherwise. The correlation between the family means for weight at birth and weight at a year, of males born in litters of three, was given as +0.63 in an earlier paper. (Wright, 1917)[5]. The difference between the undersized guinea pigs of such a family as No. 2 and the large ones of such a family as No. 13, is in fact even more marked among the adults than among the young. The demonstration of factors which affect the rate of growth at all ages has, however, no bearing on differentiation in general vigor.

The other two significant correlations connect size of litter with birth weight and gain, respectively, in the period from 1911 to 1915. Each of these correlations was +0.62 ±0.08. The correlations, in the period from 1906 to 1910, were not certainly significant, although relatively high (+0.26 and +0.37 respectively). Because of the close connection between birth weight and gain, it is evident that we are really dealing with a single correlation, one between size of litter and rate of growth (for a given size of litter). There is an indication of an interrelation here, although, as will be shown later, there is another possible explanation which must be considered.

In opposition to the hypothesis of a differentiation in general vigor, we have the evidence of the remaining 30 correlations, only 1 of which is as high as +0.30, and 11 of which are negative. The low correlations in certain cases are especially noteworthy. The percentage born alive, and the percentage of those raised to weaning, show virtually no correlation in the first period (+0.03), and only a doubtful one in the second (+0.30). It would appear that these depend, to a large extent, on independent hereditary factors. There is evidence which is brought out in Bulletin 1121 that the percentage born alive depends more on the vigor of the dam, while the percentage raised of those born alive depends more on the vigor of the young themselves. There must, of course, be important factors in common, but the effects of these seem to be neutralized by the tendency toward negative correlation which independent factors would have in this case. Factors which tend to remove the less vigorous young at or before birth tend thereby to increase the percentage raised of those born alive, if they do not also prejudice the chances of the young after birth.

But even though there may be factors in common, the differences among the families in vigor in these respects is in marked contrast to the differences between stocks of guinea pigs raised under different environmental conditions. Under unfavorable conditions both the percentage born alive and the percentage raised of those born alive tend to decline.

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[5] See footnote 2.

The lack of correlation between the two elements in fertility, size and frequency of litters (+0.04 and −0.03 in the two periods) is also surprising. Here again the hereditary factors must be largely independent of each other. A small amount of common heredity may be obscured by a tendency toward negative correlation due to independent factors. Within inbred stock large litters tend to be followed by a long delay, and fertilization immediately after the birth of a litter tends to result in a small litter. These tendencies are not very important, however, as was shown in the first part of this bulletin.

The correlations between average weight and ability to bear and raise the young successfully have more tendency to be negative than positive. The lack of correlation between percentage born alive and birth weight or gain is noteworthy because genetic differentiation with respect to these characters is beyond question. The absence of significant correlation between the percentage born alive and size of litter is important for the same reason. The other correlations which connect vitality and fertility agree in giving no significant indications of heredity of general vigor. There is finally a tendency toward negative correlation between body size and frequency of litters.

It will be seen that in general the differences among the families are of a different kind from those which distinguish individuals in a given stock or similar stocks raised under different conditions. In the latter cases we are undoubtedly dealing largely with differences in general condition. In summer and fall litters are both larger and more frequent, larger percentages of the young are born alive and also raised among those born alive, and growth is more rapid, than in winter and spring. Inspection of the yearly fluctuations in the averages of the various characters (given in Part I) shows that if the year were made the unit very high positive correlations would be obtained in all cases instead of the insignificant ones of Table 4, got by making the family the unit. This would be true even though the downward trend of all characters were eliminated. The conclusion which is forced on us by these considerations is that there is little or no differentiation among the families in general vigor, but instead a fixing in each family of particular traits in some particular combination.

A detailed study of the combinations of characters actually found in the 22 families is instructive. For this purpose it is convenient to arrange the families in the order of excellence in each character in each period of years. A division into five groups makes the relations more easy to grasp. In Table 5 the best three families in any respect are given rank A; the next five, rank B; the middle six,

rank C; the next five, rank D; and the poorest three, rank E. Family 15, which produced too few young in the second period to give significant results, is assigned ranks in the first period but is not counted in assigning ranks to the other families.

TABLE 5.—*Ranks of the families during years 1906 to 1910, and 1911 to 1915.*

[The best three are given rank A; the next five, rank B; the middle six, rank C; the next five, rank D; and the poorest three, rank E. Family 15 is given a rank in the first period only and is not counted in assigning ranks to the others. The ranks for 1906–1910 and 1911–1915 are given in succession. For example, EC means among the poorest three in 1906–1910 and middling in 1911–1915. Great changes in rank are indicated by stars.]

Family.	Per cent born alive.	Per cent raised of those born alive.	Per cent raised.	Birth weight (those raised).	Gain to 33 days.	Weight at 33 days.	Size of litter.	Litters per year.	Young per year.
1	CC	EE	ED	ED	DE	EE	EE	DE	EE
2	EC*	CA*	DB*	CE*	EE	EE	DD	EA***	EB**
3	EE	CE*	EE	BC	BA	BB	BC	DB*	CB
7	DD	DB*	EC*	DC	CC	CB	BC	CC	BB
9	DD	CC	DD	AB	AA	AA	BA	CD	BC
11	DC	EE	DE	BA	BA	BA	AA	DD	BC
13	CB	CB	CB	AA	AB	AA	AB	CC	BA
14	EE	CD	DD	CC	CB	CB	CC	CE*	CE*
15	E	B	E	C	E	D	E	D	E
17	AB	AB	AA	ED	ED	ED	DD	DC	DC
18	BB	DD	BC	BB	CC	CC	CC	BB	CC
19	DD	BD*	CD	CB	DD	DC	BB	BB	BA
20	DB*	DA**	DA**	CC	CD	CD	EC*	CD	DD
21	BD*	DB*	CC	AD**	BC	AC*	EE	BB	DD
23	AA	ED	CC	BC	BD*	BE**	BD*	AA	AB
24	CE*	BD*	BE**	DE	DC	DC	CE*	AB	AD**
31	AD**	BA	AB	CC	DC	CC	CB	ED	DD
32	BC	CC	BD*	DD	ED	DD	CD	BC	CC
34	CB	AC*	BC	BB	BE**	BD*	DD	CD	CD
35	BC	DB*	CB	DB*	DB*	DB*	DA**	DA**	DA**
36	CC	BC	BC	DD	CB	CC	AC*	BC	AC*
38	BA	AC*	AB	CA*	AB	BB	CB	EE	EE
39	CA*	BC	CA*	EE	CC	DD	DB*	AC*	CB

Inspection of Table 5 brings out clearly the tendency of the families to hold their rank with respect to each character. Changes of rank of more than one grade are indicated by stars. A shift of two grades is shown by one star, of three grades by two stars, and one case in which there was a change from E to A by three stars. There was the greatest shifting of places in the percentage raised among those born alive, but even here 12 of the 22 held their rank or changed by only one grade. The correlation between successive periods was rather low in this case, being only +0.32. In the cases of the other characters, there were from 16 to 19 of the 22 families which held their place in the sense given above or changed only one grade. The case of the frequency of litters is especially interesting, since the coefficient of correlation between successive periods (+0.25) did not appear to be significant. It is therefore surprising to find that eight of the families were of the same grade in both periods and that nine changed by only one grade, leaving only five which made conspicuous changes in rank. The low correlation is evidently due to the remarkable change in character of two families, namely, Nos. 2 and 35.

Family 2 was the poorest family in producing litters between 1906 and 1910, but tied with Family 23 for the first place in the second period. The change was nearly as great in Family 35. The correlation becomes +0.66 if these two families are omitted.

Looking through the table, we find that Families 35 and 2 made conspicuous changes in rank in several other respects. A few other families also made numerous changes. In fact, a majority of the marked cases of relative improvement or deterioration are found in Families 35, 2, 24, 20, and 21, and these include 10 of the 13 cases in which there were changes of more than two grades. There were, on the other hand, six families (1, 9, 11, 13, 17, and 18) which made no important changes and eight more with only one or two changes. We are thus led to look into the history of the families to see why it is that certain of them have changed in many respects while others have remained constant,

Careful study of the pedigrees shows that there has been a much greater revolution in the predominant lines of descent in Family 35 than in any other family. A single mating was made in the first generation of this family, but four were made in the second generation, which may be looked upon as founding four subfamilies. The smallest of these subfamilies, which during the first seven generations included only 17 per cent of the matings, suddenly began to expand at this time and produced 65 per cent of the matings made between the eighth and twelfth generations. All of these were descended from a single mating in the seventh generation. By the end of 1917 the entire family, which was one of the largest in the stock, was descended from a single mating in the twelfth generation and had reached the most advanced generation of inbreeding in any family.

With this history, it can hardly be a coincidence that Family 35 has changed in character more than any other family. It will be seen from Table 5 that Family 35 made poor records during the first period in birth weight, gain, and weight at 33 days, in size and frequency of litter, and hence in total fertility, and finally in the percentage raised of those born alive. During the second period the birth weight, gain, and weight at weaning were good; size and frequency of litters and total fertility were among the best, and the percentage born alive and the total percentage raised were good. A decline from rank B to C in the percentage born alive meant merely a change from eighth to ninth among the 22 families. Following the second period, i. e., since 1915, the relative improvement continued in every respect and the family became on the whole the most vigorous in the stock, displacing Family 13, which had previously held this position. Family 35 evidently started with relatively inferior heredity for most elements of vigor. Apparently,

however, a remarkably fortunate combination of genetic factors segregated out in one line, and this line ultimately displaced all other lines.

Family 2 had a somewhat similar history. There were many lines in the early generations, but after the seventh generation all of the matings traced back to a single pair in the fourth generation. The family began as one of the weakest in nearly every way and was absolutely the poorest in rate of gain and in frequency of litters. The successful line continued to produce small litters of undersized animals, and held the record for smallness of gains in the second period, as well as in the first. The percentage born alive, however, increased from very poor to medium, and the percentage raised of those born alive increased from medium to the very best. The most remarkable change was from the lowest in litters per year in the first period to a tie with Family 23 for the highest record in the second. Since 1915 small litters and very light weight have remained characteristic, but also frequent litters and great success in raising the young born alive. In spite of its defects it is one of the easiest families to maintain. Its ability to raise the young which are born alive seems to be correlated with high vitality thereafter.

Study of the pedigrees indicates that Family 24 must probably be considered as next to Family 35 in the extent to which there has been a shifting in the importance of lines of descent. Table 5 shows that it stands third in change of characteristics. In this case, however, the change was for the worse in most respects. Apparently a number of fairly vigorous lines were superseded by an inferior one. This would seem hardly as likely to happen as the expansion of a good line, noted in Families 35 and 2, but it is not impossible. It must be remembered that the characters of a line of descent can be determined only from the average of many individuals. At a given time the genetically inferior line might well happen to be represented by the more vigorous individuals.

Among the remaining families, Nos. 20, 21, and probably also 34, were ones in which the rather important changes in character may also well have been due to the expansion of particular lines of descent. The changes in 23 and 39 can not be explained so satisfactorily in this way. In certain cases families remained fairly true to type, even though the predominant lines of descent altered considerably. This was true of Families 1, 9, 13, 19, and 38. This, however, is not surprising. In the remaining families the original lines of descent run parallel to each other through both periods and there were few important changes in the family characteristics.

A consideration of these family histories, especially those of Families 35, 2, and 24, strengthens the argument for the inheritance of characters in which the coefficient of correlation between the suc-

cessive periods was too low to be certainly significant. The low correlation in regard to litters per year (+0.25) is, as already noted, largely due to the remarkable change from one extreme to the other in Family 2, and the only slightly less remarkable change in Family 35. But in view of the likelihood that a real genetic change took place in these families, through segregation in the early generations and expansion of one line of descent at the expense of the others, the changes in these families must not be weighed too heavily against the absence of important changes in rank in 17 other families. Similarly, in the case of the percentage raised of those born alive, and the percentage raised of all young, the changes in Families 35, 2, and 24 play a large part in making the correlations low (+0.32, +0.36).

If we attempt to arrange the families in order with respect to general vigor, there would be little hesitation in picking out Family 13 as the best. It is the only family which was average or better than average in every character in both periods. It was easily among the best families in weight and fertility, and changed from medium to good in the ability to raise the young. At the other extreme come Families 1 and 15. Family 1 was among the poorest families in the majority of characters in both periods. Family 15 was similarly poor during the first period and it is not surprising that it was the first family to become extinct, in spite of all efforts to maintain it, and that it was followed to extinction by Family 1.

Even in these families, however, we are not dealing merely with differences in general vigor. Family 13 is relatively lower in its ability to raise its young than in growth and fertility, and Families 1 and 15 each have a redeeming trait. In both the earlier and later period slightly more than the average percentage of the young were born alive in Family 1, an advantage lost through inability to rear them successfully. The situation was reversed in Family 15, which lost a larger percentage of the young at birth than any other family, but was well above the average in the percentage raised of those born alive.

When we consider the remaining families, the impossibility of ranking them in general vigor becomes at once apparent. Family 38 would be placed second to Family 13 in general vigor but for the fact that it produced litters less frequently than any other family. Owing probably to this defect, it was always a small family. Families 11 and 9 are two similar families which have a remarkable combination of vigor and weakness in different characters. They were among the best three families in both size of litter and weight, yet both of them produced litters irregularly and were unsuccessful in raising the young. The contrast was especially marked in Family 11, which led all of the families during the second period in size of litter, gain, and weight at 33 days, but was one of the three poorest families in the

percentage of young which reached weaning. Family 3 agrees with Families 9 and 11 in combining rapid growth with inability to raise the young successfully. It was doubtless this poor success in raising the young which caused Families 3 and 11 to be among the five families which were extinct at the end of 1915.

Family 2, during the second period, had a combination of characters the opposite of that in Families 9 and 11. With the smallest weight and small litters it combined the greatest regularity in producing litters and the best record in raising the young which were born alive. Family 17 was consistently of this type in most respects. During both periods it produced small litters and small pigs, but pigs which were easily raised. This combination seemed to be more fortunate than that of Families 9, 11, and 3, since Family 2 became the most numerous of all the families after 1915, and Family 17 was a large family, while, as noted above, Families 3 and 11 were among the first to become extinct and Family 9 was always a small family.

It was shown earlier that the only significant correlations between the different groups of characters were those between birth weight or gain and size of litter (+0.26 and +0.37 in the first period, both +0.62 in the second). The impossibility of considering these correlations as an indication of heredity of general vigor may be seen by comparing Families 9, 11, and 3 with Families 2 and 17. As we have just seen, the latter families appeared to be the more successful, in spite of their great inferiority in size of litter and weight.

There is a possible cause of correlation between characters which should be mentioned. It will be remembered that the experiment started with 23 different females, but only 9 males. If one of the male ancestors of several families happened to transmit two of the characters in an extreme degree, it would tend to bring about a correlation in these characters among the families, which would have no significance as an indication of inheritance of general vigor or of a common physiological factor. It may not be a coincidence that the three families which traced back in all lines (Families 9 and 11) or in the principal line (Family 13) to a certain foundation male ancestor (Male 3) should be the three leading families in both size of litter and weight. Again, two of the four families descended from Male 1 (Families 1 and 2 in the group 1, 2, 3, and 7) are characterized by remarkably small litters and light weight. If we suppose that Male 3 transmitted both large size of litter and great weight in a remarkable degree, and perhaps that the converse was true of Male 1, we can account for the correlation between these characters observed in the present data.

The other groups of families with common male ancestors, namely, Families 17 to 24, 31 and 32, 35 and 36, were not clearly differentiated, but it may well have been that Males 3, 9, and 11 were medioc-

ities genetically, heterozygous in many respects, among whose lescendants any trait was likely to segregate out. That one or two of the males transmitted extreme degrees of two characters is a mere coincidence on the view suggested above and would not be expected o happen with other characters.

The absence of correlation between the characters finds extreme llustrations in most cases. Compare, for example, Family 23, in which the young were born alive with great success, but died in unusually large numbers before weaning, with Family 13, in which the reverse was true. Families 17 and 3 have already been noted as families which were successful or failed in both respects. Families 11, 21, 19, and 1 show extremes of size and frequency of litters, combined in four different ways. Even in the case of birth weight and gain, some independence may be noted. In Family 39 the young made better gains in both periods than their birth weights indicated as most likely, while the opposite was true of Family 19.

RECORDS OF FIVE FAMILIES IN RECENT YEARS.

As already noted, most of the inbred families have been disposed of since 1915 to make room for a more intensive study of the five which have been retained, Nos. 2, 13, 32, 35, and 39, and for experiments on crossbreeding. The data for years 1916 to 1919 is presented in Bulletin 1121. It is desirable here, however, to compare the standing of the above-mentioned five families in 1916–19 with their standing in the earlier periods. This is especially true because two of these families, Nos. 2 and 35, were the ones among the original 22 which showed the greatest change in character from the first to the second period. The rank in various characters of the five remaining families is shown in Table 6 for the three periods together with rank in longevity of the males and females (1915–1918) and resistance to tuberculosis during 1919–20. The resistance to tuberculosis has been obtained in experiments in cooperation with Dr. Paul A. Lewis, of the Henry Phipps Institute. (Wright and Lewis, 1921.)[6]

The correlation between the ranks in the first and second, the first and third, and the second and third periods are shown in the last three lines of Table 6. A single correlation based on five entries does not, of course, have much significance by itself. It will be seen, however, that while the correlation between standing in the first period and the second or third is negative in almost as many cases as it is positive, all of the correlations between the second and third periods are positive, and most of them are high. Their average is +0.75, where +0.04 and +0.01 are the averages in the cases of the correlation of first with second and third period respectively. The

[6] See footnote 3.

absence of appreciable correlation between first and second periods among the five families in contrast with the significant correlation found in dealing with all 22 families (Table 3) is of course due to the large part played by Families 2 and 35 among the 5 families. It strengthens the evidence for inheritance to find that even these families became fairly well settled in relation to the other families during the second period.

Considering the separate characters the evidence for differentiation in weight is most consistent. There is close agreement between rank in weight at all ages and in both sexes. The only important exception is that Family 32 appears to produce heavy young relative to its adult weight.

The rank of the families in both size and frequency of litters appears to have become fairly well settled in the second period. Because of the negative correlation present in the five families between these elements of fertility there is not much differentiation in the product, the number of young produced per year. The perfect correlation in 1916–1919 between adult weight and size of litter is noteworthy. It will be remembered that significant correlations were found among the 22 families between birth weight or gain and size of litter in the second period. The possible explanation suggested in that case, namely that the three best families in both weight and size of litter were all derived from one male ancestor, has no application among the five families considered here. There is undoubtedly an indication of a direct physiological relation between weight and size of litter, apart, of course, from the direct (negative) effect of size of litter on the early weights, for which due correction is made by the use of indexes.

There is good evidence for differentiation in both percentage born alive and percentage raised of those born alive. Just as in the case of the two elements of fertility, there happens to be a negative correlation between the two characters among the five families, with the consequence that there is no very clear-cut differentiation in their product, the percentage raised of all births.

The longevity of the males and females born 1915–1918 was obtained by taking each interval of three months in age separately and finding the death rate among those not disposed of during the period in question. The most noteworthy feature is the marked superiority of Family 2 shown by both sexes. There was not much differentiation among the other families.

A comparison of ranks in different characters during the third period confirms the conclusion drawn from study of the 22 families in the earlier periods, namely, that there is not differentiation in general vigor, but differentiation in each characteristic separately. The number of young raised per year by a mating is perhaps the best single

measure of the efficiency of the families. There is good evidence for differentiation in this in the second and third periods. There is also rather close agreement with rank in resistance to tuberculosis. There is not, however, agreement with longevity or with weight.

TABLE 6.—*The rank of five inbred families in various characteristics in three successive periods, 1906 to 1910, 1911 to 1915, 1916 to 1919.*

[The correlations between these ranks in the first and second, the first and third, and the second and third periods are shown below. The ranks of the families in longevity of males and females, born from 1915 to 1918, and in resistance to tuberculosis (1919–1920) are shown in the three columns at the right.]

Family.	Percentage born alive.	Percentage raised of those born alive.	Percentage raised.	Birth weight of those raised.	Gain to 33 days.	Adult weight. Males.	Adult weight. Females.	Size of litters.	Litters per year.	Young per year.	Young raised per year.	Longevity. Males.	Longevity. Females.	Resistance to tuberculosis.
2	5–5–5	4–1–2	5–4–2	2–5–5	5–5–5	2–5–4	5–5–5	4–4–4	5–1–1	5–4–2	5–3–2	–1	–1	–2
13	4–2–4	2–2–3	4–2–4	1–1–1	1–1–1	1–1–1	1–2–1	1–2–1	3–3–4	1–2–3	1–2–3	–3	–2	–4
32	1–4–2	3–5–5	1–5–5	3–3–3	4–4–3	4–4–5	3–4–4	2–5–5	2–4–3	2–5–4	2–5–4	–2	–3	–3
35	2–3–3	5–3–1	3–3–1	4–2–2	3–2–2	3–2–2	4–1–2	3–1–2	4–2–2	4–1–1	4–1–1	–4	–4	–1
39	3–1–1	1–4–4	2–1–3	5–4–4	2–3–4	5–3–3	2–3–3	5–3–3	1–5–5	3–3–5	3–4–5	–5	–5	–5
Correlations.														
1st–2d	+0.10	–0.30	–0.10	+0.30	+0.90	+0.30	+0.40	+0.10	–1.00	0.00	–0.20	......	......	......
1st–3d	+ .70	– .70	– .50	+ .30	+ .70	+ .50	+ .70	+ .30	– .90	– .50	– .50	......	......	......
2d–3d	+ .60	+ .70	+ .20	+1.00	+ .90	+ .90	+ .90	+ .90	+ .90	+ .50	+ .80	......	......	......

SUMMARY.

Part II deals with the differences found among 23 inbred families, derived wholly or in part from the same original line-bred stock.

It is found that a certain color and pattern tended to become fixed automatically in each line of descent. In certain cases an entire family came to breed true to a given color and pattern. In other cases subfamilies derived from different matings in the early generations of a family each developed a characteristic color and type of pattern to which they came to breed true.

In a similar way, certain subfamilies became differentiated from other subfamilies and from other families by developing a strong tendency toward reappearance of an ancestral fourth toe on the hind feet.

Relatively few monstrosities were produced either by the inbred families or by the controls. The tendency to produce a given type of monstrosity has been characteristic of certain families. Such a tendency has had no connection with the vigor of the family in other respects. The two feeblest families gave few or no pronounced abnormalities, while about 30 per cent of the cyclopean monsters were produced by the most vigorous family. Another family produced most of the eyeless young and another had several defective young with rudimentary legs. There was evidence of heredity within the families, of the tendency to produce these abnormalities. There was no evidence that inbreeding has any specific causal connection with

the origin of the monsters. Inbreeding seems merely to have brought to light genetic traits in the original stock.

Although most of the families came from the same line-bred stock a striking differentiation with respect to traits connected with vigor was found among them. These traits included size and frequency of litters, percentage born alive and raised of those born alive, birth weight, and gain to 33 days. The differences between the families were greater than could be due to chance, and increased as the inbreeding progressed and the families became more homogeneous through the elimination of early branches from the main lines of descent. The families tended to keep the same rank with respect to each character. The correlation between the average grades in the early and later histories of the families was high in respect to size of litter, birth weight, and gain. It was high enough to be significant in the case of the percentage born alive. The correlations were positive but of doubtful significance for the percentage raised of the young born alive and for the frequency of litters. A detailed study of the individual families, however, showed that the correlations would have been higher and all would have been significant but for two or three families in which there had been reversal of relative importance among the subfamilies and in which therefore a change in rank in all or many respects was not surprising. Recent evidence indicates that even these families have now become fixed in their characteristics. The conclusion seems warranted that there was heredity of all of the traits studied.

There did not, however, appear to be heredity of general vigor. The average vigor of a family in one respect was found to be in the main independent of its vigor in other respects. Thus the average success of the families in raising their young was not correlated with weight or with size or frequency of litters. Neither was weight correlated with regularity in producing litters. There was not even a significant correlation between the percentage born alive and the percentage of those raised, although success or failure in each separately was undoubtedly characteristic of families. Similarly there was no correlation between the average size of litter and litter frequency. The only apparent exception, outside of high correlations between birth weight, gain, and year weight, was in a high correlation between weight and size of litter, for which there is undoubtedly some indication of a physiological interrelation.

The study of the individual families brought out interesting examples of extreme vigor throughout the history of a family in certain respects, associated with extreme weakness in others, as well as cases in which all kinds of vigor or all kinds of weakness were combined.

While the characteristics of a family probably reflected to a considerable extent simply the average of the genetic factors in the original pair, there was considerable evidence of segregation in the early generations in characters associated with vigor, just as in the cases of color, pattern, polydactylism, and tendency to produce monstrosities. In one family which was very weak in most respects in the early generations, a single line of descent began to expand in the eighth generation until it composed the entire family. This line revealed itself as the most vigorous in nearly all respects in the entire stock of inbred families. There were other less extreme cases of this sort.

The study brought out a striking contrast between the effects on vigor of hereditary and environmental factors. Favorable or unfavorable conditions affect alike growth, mortality among the young, and fertility, in all their aspects. On the other hand, hereditary factors which affect each character by itself appear to be much more important than ones which affect general vigor.

Finally the study illustrates what is one of the most important results of inbreeding, namely, the bringing to light and fixing of characters in a family. In the case of color the mechanism of heredity is thoroughly understood and the automatic fixation of type is a necessary consequence of this mechanism. The similarity of the phenomena in the other characters makes it probable that the mechanism is essentially the same in all cases.

APPENDIX.

TABLE 7.—*Data on the fertility of the different inbred families, 1906 to 1910.*

Family.	Size of litter.								Number of mating-years.	Number of litters.	Number of young.	Average size of litter.	Litters per year.	Young per year.
	1	2	3	4	5	6	7	8						
1....	11	13	15	3	1	.....	.....	.....	10.9	43	99	2.30	3.94	9.08
2....	22	40	28	20	7	2	.....	.....	37.8	119	313	2.63	3.15	8.28
3....	13	41	45	29	8	5	1	.....	35.0	142	423	2.98	4.06	12.09
7....	14	47	57	38	11	3	2	.....	40.9	172	518	3.01	4.21	12.67
9....	13	21	33	26	8	3	.....	.....	25.6	104	316	3.04	4.06	12.34
11....	17	45	76	56	21	5	1	.....	56.2	221	701	3.17	3.93	12.47
13....	19	71	61	38	37	5	.....	.....	56.8	231	711	3.08	4.07	12.52
14....	19	41	41	27	9	1	2	.....	33.4	140	397	2.83	4.19	11.89
15....	12	28	25	8	1	.....	.....	.....	18.9	74	180	2.43	3.92	9.52
17....	25	52	31	19	14	3	1	.....	35.7	145	393	2.71	4.06	11.01
18....	14	31	31	18	7	5	.....	.....	24.9	106	306	2.89	4.26	12.29
19....	11	11	22	10	5	0	1	1	14.4	61	179	2.93	4.24	12.43
20....	20	35	16	9	4	3	.....	.....	20.6	87	212	2.44	4.22	10.29
21....	12	25	23	9	2	.....	.....	.....	16.6	71	177	2.49	4.28	10.66
23....	11	14	16	11	7	2	.....	.....	14.0	61	178	2.92	4.36	12.71
24....	46	65	90	45	22	6	1	.....	60.9	275	779	2.83	4.52	12.79
31....	19	30	36	28	7	2	1	.....	34.4	123	353	2.87	3.58	10.26
32....	43	109	121	63	28	3	.....	.....	86.3	367	1,034	2.82	4.25	11.98
34....	2	20	15	4	4	.....	.....	.....	10.7	45	123	2.73	4.21	11.50
35....	23	43	50	23	10	5	.....	.....	38.6	154	431	2.80	3.99	11.17
36....	15	35	61	34	21	5	1	1	40.0	173	554	3.20	4.33	13.85
38....	15	31	44	21	9	2	.....	.....	34.9	122	350	2.87	3.50	10.03
39....	11	16	17	7	1	1	.....	.....	11.6	53	133	2.51	4.57	11.47

TABLE 8.—*Data on the fertility of the different inbred families, 1911 to 1915.*

Family.	Size of litter.							Number of mating-years.	Number of litters.	Number of young.	Average size of litter.	Litters per year.	Young per year.
	1	2	3	4	5	6	7						
1	16	11	7	.....	.....	.....	.....	12.6	34	59	1.74	2.70	4.68
2	42	97	83	16	8	.....	.....	64.7	246	589	2.39	3.80	9.10
3	19	30	33	6	4	1	1	25.9	94	235	2.50	3.63	9.07
7	49	67	70	33	11	3	1	67.6	234	605	2.58	3.46	8.95
9	26	46	58	30	7	5	.....	55.2	172	477	2.77	3.12	8.64
11	17	38	54	36	9	1	.....	53.8	155	450	2.90	2.88	8.36
13	42	96	134	63	12	3	.....	100.7	350	966	2.76	3.48	9.59
14	12	21	26	7	.....	.....	.....	25.9	66	160	2.42	2.55	6.18
15	.....	2	1	.....	.....	.....	.....	1.2	3	7	.....	.....	.....
17	71	117	72	38	6	1	1	88.3	306	716	2.34	3.47	8.11
18	32	72	46	23	6	2	1	51.8	182	455	2.50	3.51	8.78
19	24	35	41	23	5	3	.....	37.5	131	352	2.69	3.49	9.39
20	27	61	52	15	6	.....	1	51.2	162	402	2.48	3.16	7.85
21	49	61	28	8	2	.....	.....	41.2	148	297	2.01	3.59	7.21
23	41	47	43	14	6	.....	.....	39.7	151	350	2.32	3.80	8.82
24	49	55	39	15	4	.....	1	46.1	163	363	2.23	3.54	7.87
31	33	39	52	28	8	5	.....	56.9	165	449	2.72	2.90	7.89
32	50	107	84	26	6	1	.....	78.9	274	656	2.39	3.47	8.31
34	20	31	22	13	2	.....	.....	28.7	88	210	2.39	3.07	7.32
35	49	90	97	64	15	9	1	87.2	325	912	2.81	3.73	10.48
36	50	107	88	42	6	3	.....	86.1	296	744	2.51	3.44	8.64
38	25	45	59	21	6	2	.....	62.6	154	418	2.71	2.46	6.68
39	37	91	110	44	14	.....	1	87.0	297	802	2.70	3.41	9.22

TABLE 9.—*The percentage born alive in the different inbred families.*

[The average in litters of each size and an index (litters of 1, 2, 3, and 4, weighted 1, 3, 4, and 2 respectively), 1906 to 1910 and 1911 to 1915.]

Family.	Size of litter, 1906–1910.						Index.	Size of litter, 1911–1915.						Index.
	1	2	3	4	5	6		1	2	3	4	5	6	
	Per c't.	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*		*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	
1	100.0	76.9	95.6	91.7	100.0	......	89.7	68.8	95.5	85.7	......	......	......	85.9
2	72.7	82.5	88.1	75.0	94.3	82.3	82.3	81.0	90.2	84.3	76.6	72.5	......	84.2
3	76.9	79.3	83.7	81.0	95.0	43.3	81.2	84.2	83.3	82.8	50.0	20.0	00.0	76.5
7	85.7	85.1	87.7	77.0	70.9	50.0	84.6	81.6	83.6	81.4	83.3	72.7	61.1	82.5
9	84.6	90.5	84.8	81.7	85.0	94.4	85.9	80.8	84.8	78.7	83.3	77.2	50.0	81.7
11	70.6	90.2	88.2	84.4	78.1	63.3	86.3	76.5	89.5	88.3	66.7	48.9	83.3	83.2
13	79.0	88.7	88.5	88.2	86.0	73.3	87.6	90.5	87.5	89.8	85.3	78.3	94.4	88.3
14	84.2	80.5	87.0	82.4	82.2	33.3	83.9	83.3	90.5	76.9	67.9	......	......	79.8
15	83.3	78.6	77.3	78.1	00.0	......	78.5	......	50.0	66.7	......	......	......	......
17	96.0	95.2	92.5	92.1	95.7	61.1	93.6	83.1	93.6	89.4	82.9	50.0	83.3	88.7
18	85.7	90.3	96.8	95.8	77.2	90.0	93.5	75.0	90.3	92.0	87.0	53.3	33.3	88.8
19	90.9	77.3	87.9	85.0	92.0	......	84.4	91.7	94.3	77.2	60.9	80.0	61.1	80.5
20	85.0	84.3	85.4	86.1	90.0	61.1	85.2	85.2	85.2	89.1	93.3	83.3	......	88.4
21	100.0	88.0	91.3	94.4	70.0	......	91.8	75.5	82.8	85.7	71.0	10.0	......	81.1
23	81.8	96.4	93.8	95.5	88.6	66.7	93.7	80.5	87.2	93.8	92.9	90.0	......	90.3
24	87.0	90.0	89.3	85.0	78.2	91.7	88.4	67.4	75.5	82.9	78.3	40.0	......	78.2
31	94.7	96.7	93.5	93.8	71.4	41.7	94.6	66.7	89.8	78.2	91.1	95.0	83.3	83.1
32	95.4	92.7	90.6	84.9	72.2	66.7	90.6	94.0	85.5	89.7	71.2	56.7	16.7	85.2
34	50.0	95.0	93.3	93.8	75.0	......	89.6	75.0	90.3	90.9	84.6	40.0	......	87.9
35	82.6	98.8	93.3	75.0	60.0	70.0	90.2	71.4	88.9	91.7	83.2	64.0	46.2	87.1
36	93.3	94.3	86.9	78.0	81.9	90.0	88.0	92.0	91.6	87.9	73.2	60.0	55.6	86.5
38	93.3	93.6	97.0	84.5	86.7	83.3	93.1	88.0	93.3	92.7	77.4	53.3	50.0	89.4
39	90.9	94.8	84.3	85.7	0.0	0.0	88.4	94.6	94.0	91.8	85.8	64.3	......	91.5

TABLE 10.—*The percentage raised to 33 days of the young born alive in the different inbred families.*

[The average in litters of each size and the index (see Table 9), 1906 to 1910 and 1911 to 1915.]

Family.	Size of litter, 1906–1910.						Index.	Size of litter, 1911–1915.						Index.
	1	2	3	4	5	6		1	2	3	4	5	6	
	Per c't.	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*		*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	
1....	81.8	80.0	86.0	63.6	100.0	......	79.3	72.7	81.0	77.8	......	......	......	77.1
2....	100.0	90.9	85.1	88.3	93.9	80.0	89.0	97.0	90.6	86.2	89.8	65.5	......	89.3
3....	90.0	84.6	92.0	89.4	78.9	76.9	89.1	62.5	78.0	74.4	83.3	100.0	......	76.1
7....	83.3	85.0	86.0	89.7	71.8	88.9	86.2	80.0	90.2	89.5	80.9	80.0	81.8	87.0
9....	100.0	89.5	88.1	88.2	79.4	41.2	89.7	76.2	89.7	81.0	87.0	66.7	53.3	84.3
11....	83.3	80.2	90.0	88.3	86.6	68.4	86.1	84.6	79.4	76.9	65.6	63.6	60.0	76.2
13....	73.3	88.1	95.1	93.3	85.5	81.8	90.5	78.9	82.8	90.8	85.6	66.0	88.2	86.2
14....	81.2	90.9	92.5	91.0	91.9	100.0	90.6	100.0	84.2	73.3	78.9	......	......	80.4
15....	100.0	90.9	89.6	88.0	......	......	90.7	......	100.0	50.0	......	......	......	......
17....	95.8	96.0	97.7	97.1	85.6	90.9	96.9	89.8	88.1	89.6	76.2	40.0	60.0	86.5
18....	66.7	94.6	90.0	85.5	88.9	77.8	88.2	87.5	91.5	76.4	72.5	93.8	0.0	81.3
19....	100.0	88.2	93.1	97.0	69.6	......	93.1	68.2	77.3	91.6	73.2	65.0	54.5	81.3
20....	94.1	86.4	90.2	83.9	94.4	90.9	88.2	91.3	91.3	87.0	87.5	80.0	......	88.8
21....	75.0	95.4	87.3	79.4	85.7	......	86.9	91.9	91.1	87.5	82.6	100.0	......	88.0
23....	88.9	88.9	73.3	90.5	83.9	87.5	83.0	87.9	73.2	81.8	78.8	74.1	......	79.2
24....	85.0	92.3	92.5	90.2	91.8	90.9	91.2	78.8	79.5	76.3	74.5	87.5	......	77.2
31....	88.9	94.8	91.1	89.5	88.0	60.0	91.7	90.9	87.1	91.0	83.3	73.7	68.0	88.2
32....	97.6	88.6	91.5	86.4	81.2	100.0	90.2	85.1	85.8	85.4	73.0	58.8	0.0	83.0
34....	100.0	86.8	97.6	93.3	80.0	......	93.7	86.7	73.2	86.7	84.1	100.0	......	82.1
35....	78.9	89.4	87.1	92.8	90.0	71.4	88.1	80.0	88.9	87.3	81.2	79.2	60.0	85.8
36....	100.0	93.9	88.0	86.8	84.9	70.4	90.7	78.3	86.7	83.2	78.7	88.9	90.0	83.1
38....	82.9	93.1	94.5	85.9	84.6	60.0	92.2	81.8	84.5	80.5	81.5	62.5	66.7	82.0
39....	90.0	86.7	97.7	83.3	......	......	90.8	77.1	92.4	85.5	70.8	68.9	......	83.8

TABLE 11.—*The percentage raised to 33 days of all young (born dead or alive) in the different inbred families.*

[The average in litters of each size and the index (see Table 9), 1906 to 1910 and 1911 to 1915.]

Family.	Size of litter, 1906–1910.						Index.	Size of litter, 1911–1915.						Index.
	1	2	3	4	5	6		1	2	3	4	5	6	
	Per c't.	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*		*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	
1....	81.8	61.5	82.2	58.3	100.0	......	71.2	50.0	77.3	66.7	......	......	......	66.6
2....	72.7	75.0	75.0	66.2	88.6	66.7	73.0	78.6	81.9	72.7	68.8	47.5	......	75.3
3....	69.2	67.1	77.0	72.4	75.0	33.3	72.3	52.6	65.0	61.6	41.7	20.0	0.0	57.7
7....	71.4	72.3	75.4	69.1	50.9	44.4	72.8	65.3	75.4	72.8	67.4	58.2	50.0	71.8
9....	84.6	81.0	74.7	72.1	67.5	38.9	77.1	61.5	76.1	63.8	72.5	51.4	26.7	69.0
11....	58.8	72.2	79.4	74.6	67.6	43.3	74.2	64.7	71.0	67.9	43.8	31.1	50.0	63.7
13....	57.9	78.2	84.2	82.2	73.5	60.0	79.4	71.4	72.4	81.6	73.0	51.7	83.3	76.1
14....	68.4	73.2	80.5	75.0	75.6	33.3	76.0	83.3	76.2	56.4	53.6	......	......	64.2
15....	83.3	71.4	69.3	68.8	0.0	......	71.2	......	50.0	33.3	......	......	......	......
17....	92.0	91.3	90.4	89.5	82.8	55.6	90.7	74.6	82.5	80.1	63.2	20.0	50.0	76.9
18....	57.1	85.5	87.1	81.9	68.6	70.0	82.6	65.6	82.6	70.3	63.0	50.0	0.0	72.1
19....	90.9	68.2	81.8	82.5	64.0	......	78.8	62.5	72.8	70.7	44.6	52.0	33.3	65.3
20....	80.0	72.8	77.1	72.2	85.0	55.6	75.1	77.8	77.9	77.6	81.7	66.7	......	78.5
21....	75.0	84.0	79.7	75.0	60.0	......	79.6	69.4	75.4	75.0	59.4	10.0	......	71.4
23....	72.7	85.6	68.8	86.4	74.3	58.3	77.8	70.7	63.8	76.7	73.2	66.7	......	71.5
24....	73.9	83.1	82.6	76.7	71.8	83.3	80.7	53.1	60.0	63.2	58.3	35.0	......	60.3
31....	84.2	91.7	85.2	83.9	62.8	25.0	86.8	60.6	78.2	71.2	75.9	70.0	56.7	73.2
32....	93.0	82.1	82.9	73.4	58.5	66.7	81.8	80.0	73.3	76.6	51.9	33.3	0.0	71.0
34....	50.0	82.5	91.1	87.5	60.0	......	83.7	65.0	66.1	78.8	71.2	40.0	......	72.1
35....	65.2	88.4	81.3	69.6	54.0	50.0	79.5	57.1	80.0	80.1	67.6	50.7	27.8	75.3
36....	93.3	88.6	76.5	67.6	69.5	63.3	80.0	72.0	79.4	73.1	58.3	53.3	50.0	71.9
38....	86.7	87.1	91.7	72.6	73.3	50.0	86.0	72.0	78.9	74.6	63.1	33.3	33.3	73.3
39....	81.8	81.2	82.4	71.4	0.0	0.0	79.8	73.0	86.8	78.5	60.8	44.3	......	76.9

TABLE 12.—*The average birth weight of all young born (dead or alive) in the different inbred families.*

[The average in litters of each size and the index (see Table 9), 1906 to 1910 and 1911 to 1915.]

Family.	Size of litter, 1906–1910.						Index.	Size of litter, 1911–1915.						Index.
	1	2	3	4	5	6		1	2	3	4	5	6	
	Per c't.	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*		*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	*Per c't.*	
1	99.1	78.7	72.1	59.5	72.5	......	74.3	103.9	89.9	65.9	......	......	......	76.3
2	108.1	86.3	79.1	71.1	63.6	58.7	82.6	97.8	82.9	67.1	59.4	60.5	......	73.4
3	111.4	91.7	79.5	70.8	67.1	57.6	84.6	104.5	88.7	73.1	67.0	49.5	27.8	79.7
7	100.9	91.3	78.5	67.0	67.1	58.7	82.3	103.5	90.5	78.6	69.0	59.8	56.7	82.7
9	107.6	99.7	82.2	76.0	65.0	64.5	88.8	107.6	94.2	79.3	75.3	64.5	55.5	85.5
11	105.7	90.6	81.0	74.6	63.2	57.2	85.1	108.6	95.3	83.5	67.7	59.2	59.5	86.4
13	107.7	101.2	83.0	76.0	71.1	64.1	89.5	113.5	96.5	82.7	71.7	64.0	61.2	87.7
14	100.8	88.5	80.9	69.0	67.8	66.2	82.8	103.7	93.3	74.3	69.1	......	......	81.9
15	122.8	90.5	83.0	68.4	40.5	......	86.3	......	94.5	91.2	......	......	......	......
17	105.7	86.4	74.1	68.6	63.2	55.1	79.9	101.0	88.1	72.3	62.4	53.8	59.5	77.9
18	112.4	95.3	85.0	71.0	69.9	56.2	88.0	110.1	95.3	83.2	70.7	69.0	47.0	87.0
19	110.1	85.5	78.7	75.9	68.9	......	83.3	112.8	97.1	80.6	65.4	71.3	62.8	85.5
20	109.5	85.3	77.6	72.5	62.0	59.5	82.1	102.3	94.0	78.0	69.5	62.8	......	83.5
21	112.0	96.7	82.2	76.2	60.5	......	88.3	96.1	87.8	75.8	65.4	57.5	......	79.4
23	103.6	96.6	83.0	73.4	67.7	64.5	87.2	105.3	91.2	78.8	64.0	58.5	......	82.2
24	103.8	89.2	77.8	67.2	62.9	59.8	81.7	100.1	81.6	71.1	62.2	59.0	......	75.4
31	111.9	95.3	82.3	69.3	61.3	52.8	86.6	107.0	91.9	74.4	67.5	59.5	54.5	81.5
32	105.0	90.0	75.8	68.9	57.5	50.6	81.6	103.1	85.5	74.8	62.1	56.8	47.8	78.3
34	94.5	93.3	86.9	83.3	65.0	......	88.9	96.5	91.6	81.3	73.0	58.5	......	84.3
35	104.5	90.1	76.0	69.0	59.2	55.1	81.7	97.6	94.8	81.0	70.0	63.8	54.3	84.6
36	107.4	88.9	77.9	70.2	63.2	55.5	82.6	105.3	91.2	74.1	63.0	62.1	53.4	80.1
38	107.2	91.1	81.5	71.0	63.2	57.0	84.9	118.5	98.4	81.9	69.6	62.2	63.7	88.1
39	95.4	83.9	74.1	65.6	48.5	44.5	77.5	96.9	83.8	74.8	63.5	53.5	......	77.5

TABLE 13.—*The average birth weight of young raised to 33 days in the different inbred families.*

[The average in litters of each size and the index (see Table 9), 1906 to 1910 and 1911 to 1915.]

Family.	Size of litter, 1906–1910.						Index	Size of litter, 1911–1915.						Index
	1	2	3	4	5	6		1	2	3	4	5	6	
	Grams.	*Grams.*	*Grams*	*Grams.*	*Grams*	*Grams.*		*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	
1	104.5	88.9	74.8	65.9	72.5	......	80.2	112.0	95.1	69.5	......	......	......	81.1
2	110.7	93.2	81.2	73.9	64.8	60.7	86.3	102.1	83.4	70.3	61.1	64.5	......	75.6
3	121.2	97.4	82.4	72.1	71.7	61.5	88.7	114.5	96.8	77.9	75.5	74.5	......	86.8
7	106.5	95.5	81.3	71.1	68.8	63.3	86.0	109.2	92.8	81.8	71.9	64.8	57.8	85.9
9	110.9	101.6	85.9	78.9	66.9	73.1	91.7	120.1	98.1	83.8	76.9	67.8	62.0	90.3
11	114.5	95.6	83.0	77.8	67.9	63.7	88.9	117.1	99.3	86.8	74.3	72.4	57.8	91.1
13	119.0	105.4	86.3	77.9	73.5	64.5	93.6	119.2	102.0	85.7	73.7	71.9	63.2	91.5
14	112.2	90.0	83.7	72.8	71.0	79.5	86.3	105.5	96.1	79.7	74.5	......	......	86.2
15	124.5	90.7	85.7	69.0	......	......	87.7	......	114.5	84.5	......	......	......	......
17	107.1	87.3	76.3	69.9	64.7	65.5	81.4	103.6	89.6	74.3	65.9	67.8	61.2	80.1
18	112.0	97.7	87.1	74.0	72.8	57.8	90.1	112.6	97.1	86.6	74.0	77.8	......	89.8
19	113.5	92.5	83.4	75.7	70.7	......	87.6	120.5	99.2	83.6	74.7	81.4	66.2	90.2
20	110.7	89.4	83.1	78.7	63.3	64.5	86.9	105.5	93.9	79.6	69.8	65.5	......	84.5
21	118.9	97.3	84.1	77.5	67.8	......	90.2	98.3	88.1	75.8	66.1	44.5	......	79.8
23	112.0	96.6	86.3	74.8	69.9	68.8	89.7	109.3	94.0	80.0	65.7	63.5	......	84.3
24	105.4	91.5	79.3	70.7	65.8	60.8	83.9	100.7	83.3	75.5	66.2	57.4	......	78.5
31	113.3	96.5	84.2	71.1	66.3	64.5	88.2	110.5	95.3	78.7	68.9	61.3	58.0	84.9
32	107.7	93.0	78.3	70.3	59.5	53.7	84.1	106.7	88.5	77.0	67.1	60.5	......	81.4
34	84.5	95.7	89.1	83.1	70.3	......	89.4	102.2	94.7	84.9	78.4	59.5	......	87.6
35	107.8	89.9	78.7	73.3	61.9	58.5	83.9	107.0	97.0	82.1	72.2	65.8	61.8	87.1
36	107.4	91.7	82.3	72.3	65.3	60.1	85.6	108.7	92.6	76.0	66.9	63.3	66.7	82.4
38	107.6	93.4	82.4	76.1	66.6	61.2	87.0	124.5	99.7	83.9	75.3	74.5	64.5	91.0
39	97.8	88.3	75.7	72.0	......	......	81.0	96.7	85.7	76.9	66.2	56.7	......	79.4

TABLE 14.—*The average gain between birth and 33 days, in the different inbred families.*

[The average in litters of each size and the index (see Table 9), 1906 to 1910 and 1911 to 1915.]

Family.	Size of litter, 1906–1910.						Index	Size of litter, 1911–1915.						Index
	1	2	3	4	5	6		1	2	3	4	5	6	
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*		*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	
......	207.2	158.1	144.4	152.2	173.0	....	156.4	162.5	157.9	102.9	......	......	......	126.2
......	158.8	162.6	144.8	142.4	95.0	101.3	151.1	134.1	137.5	118.1	101.6	112.4	......	122.2
......	208.3	187.7	161.5	138.8	130.5	138.0	169.5	189.0	173.2	156.5	154.0	155.0	......	164.2
......	181.0	179.0	150.7	145.1	140.0	116.2	161.1	160.9	161.5	148.0	121.6	129.7	142.8	148.0
......	229.6	189.7	179.3	153.8	158.2	127.8	182.4	215.6	186.8	148.0	134.5	140.6	130.0	163.7
......	205.0	191.7	154.3	159.5	125.0	119.6	171.6	201.4	194.3	157.1	139.0	132.8	158.4	169.1
......	212.3	206.8	169.6	161.2	138.6	127.2	183.4	207.0	178.7	150.9	133.3	129.9	93.0	161.4
......	217.3	178.2	167.0	136.7	139.7	170.0	169.3	192.0	164.0	140.7	121.7	......	......	149.0
......	225.0	165.3	147.3	125.9	....	....	156.2	....	115.0	165.0	......	......	......	......
......	163.3	158.8	159.6	124.3	120.3	114.0	152.7	175.3	155.4	131.8	118.8	121.7	115.0	140.7
......	187.5	177.5	161.2	153.5	140.0	123.1	167.1	169.3	151.7	139.8	127.5	167.7	......	143.9
......	212.0	154.3	157.6	131.4	121.3	....	156.8	153.0	160.9	127.5	122.1	101.9	93.3	139.0
......	182.6	167.7	158.3	147.7	114.4	131.0	161.4	169.7	155.8	129.1	100.9	98.0	......	135.6
......	217.3	192.7	166.8	153.5	151.7	....	177.0	190.0	161.6	137.2	123.4	145.0	......	147.0
......	215.0	185.4	165.0	132.1	137.3	123.6	169.5	176.8	155.8	124.3	102.8	125.0	......	134.7
......	172.3	169.1	153.5	135.8	135.6	111.4	156.5	171.1	153.5	146.4	131.3	72.1	......	148.0
......	201.2	167.9	156.6	135.8	139.6	131.7	160.3	171.0	162.7	145.8	118.5	117.5	143.3	147.9
......	180.3	168.2	149.3	137.0	128.0	132.5	155.6	165.8	159.7	131.1	129.4	139.0	......	142.9
......	165.0	169.0	172.6	180.7	147.5	....	172.4	116.5	139.2	133.8	137.9	100.0	......	134.5
......	184.4	164.9	151.4	138.9	147.6	141.7	156.2	162.5	161.9	143.8	129.9	131.6	129.0	148.3
......	192.1	165.5	163.1	140.9	136.5	143.1	162.3	188.6	159.5	141.9	132.2	146.2	76.1	149.9
......	200.4	175.4	178.3	168.8	127.3	125.0	177.7	223.9	170.1	152.1	131.2	123.0	95.0	160.5
......	185.0	184.3	150.5	152.5	....	....	164.1	181.0	160.3	144.3	112.3	117.3	......	146.4

TABLE 15.—*The average weight at 33 days in the different inbred families.*

[The average in litters of each size and the index (see Table 9), 1906 to 1910 and 1911 to 1915.]

Family.	Size of litter, 1906–1910.						Index	Size of litter, 1911–1915.						Index
	1	2	3	4	5	6		1	2	3	4	5	6	
	Grams.	*Grams.*	*Grams.*	*Grams*	*Grams.*	*Grams.*		*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	
......	311.7	247.0	219.2	218.1	245.5	....	236.6	274.5	253.0	172.4	......	......	......	207.3
......	269.5	255.8	226.0	216.3	159.8	162.0	237.4	236.2	220.9	188.4	162.7	176.9	......	197.8
......	329.5	285.1	243.9	210.9	202.2	199.5	258.2	303.5	270.0	234.4	229.5	229.5	......	251.0
......	287.5	274.5	232.0	216.2	208.8	179.5	247.1	270.1	254.3	239.8	193.5	194.5	200.6	233.9
......	340.5	291.3	265.2	232.7	225.1	200.9	274.1	335.7	284.9	231.8	211.3	208.4	192.0	254.0
......	319.5	287.3	237.3	237.3	192.9	183.3	260.5	318.6	293.6	243.9	213.3	205.2	216.2	260.2
......	331.3	312.2	255.9	239.1	212.1	191.7	277.0	326.2	280.7	236.6	207.0	201.8	156.2	252.9
......	329.5	268.2	250.7	209.5	210.7	249.5	255.6	297.5	260.1	220.4	196.2	......	......	235.2
......	349.5	256.0	233.0	194.9	....	....	243.9	....	229.5	249.5	......	......	......	......
......	270.4	246.1	235.9	194.2	185.0	179.5	234.1	278.9	245.0	206.1	184.7	189.5	176.2	220.8
......	299.5	275.2	248.3	227.5	212.8	180.9	257.3	281.9	248.8	226.4	201.5	245.5	......	233.7
......	325.5	246.8	241.0	207.1	192.0	....	244.4	273.5	260.1	211.1	196.8	183.3	159.5	229.2
......	293.3	257.1	241.4	226.4	177.7	195.5	248.3	275.2	249.7	208.7	170.7	163.5	......	220.1
......	336.2	290.0	250.9	231.0	219.5	....	267.2	288.3	249.7	213.0	189.5	189.5	......	226.8
......	327.0	282.0	251.3	206.9	207.2	192.4	259.2	286.1	249.8	204.3	168.5	188.5	......	219.0
......	277.7	260.6	232.8	206.5	201.4	172.2	240.4	271.8	236.8	221.9	197.5	129.5	......	226.5
......	314.5	264.4	240.8	206.9	205.9	196.2	248.5	281.5	258.0	224.5	187.4	178.8	201.3	232.8
......	288.0	261.2	227.6	207.3	187.5	186.2	239.7	272.5	248.2	208.1	196.5	199.5	......	224.3
......	249.5	264.7	261.7	263.8	217.8	....	261.8	218.7	233.9	218.7	212.7	159.5	......	222.1
......	292.2	254.8	230.1	212.2	209.5	200.2	240.1	269.5	258.9	225.9	202.1	197.4	190.8	235.4
......	299.5	257.2	245.4	213.2	201.8	203.2	247.9	297.3	252.1	217.9	199.1	209.5	142.8	232.3
......	308.0	268.8	260.7	244.9	203.4	186.2	264.7	348.4	269.8	236.0	206.5	197.5	159.5	251.5
......	282.8	272.6	226.2	224.5	....	....	245.4	277.7	246.0	221.2	178.5	174.0	......	225.8

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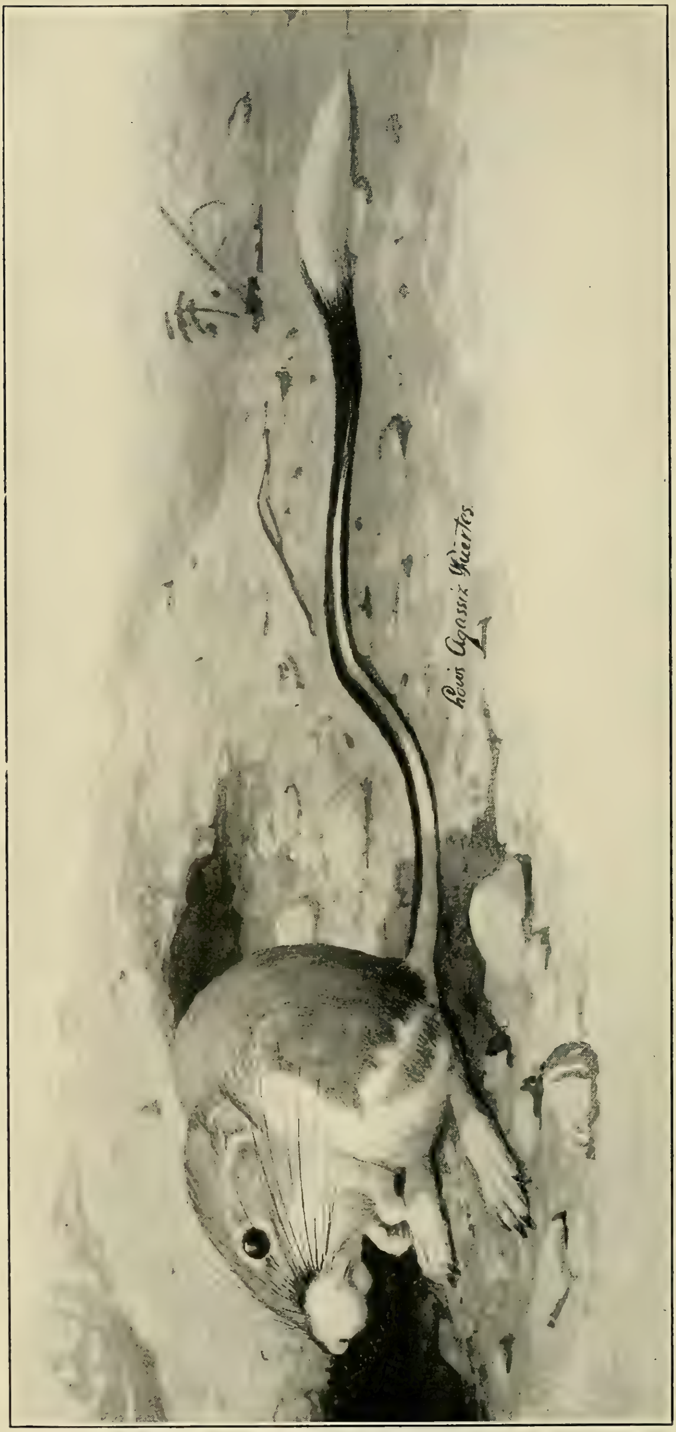

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BANNER-TAILED KANGAROO RAT (DIPODOMYS SPECTABILIS MERRIAM).

From *Dipodomys merriami* Mearns and subspecies, which occur over much of its range, this form is easily distinguished by its larger size and the conspicuous white brush on the tail.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1091

Also Technical Bulletin No. 1 of the
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LIFE HISTORY OF THE KANGAROO RAT,

Dipodomys spectabilis spectabilis Merriam.

' CHARLES T. VORHIES, *Entomologist, Agricultural Experiment Station, University of Arizona;* and WALTER P. TAYLOR, *Assistant Biologist, Bureau of Biological Survey, U. S. Department of Agriculture.*

CONTENTS.

IMPORTANCE OF RODENT GROUPS.

AS THE serious character of the depredations by harmful rodents is recognized, State, Federal, and private expenditures for their ntrol increase year by year. These depredations include not only e attacks by introduced rats and mice on food materials stored in anaries, warehouses, commercial establishments, docks, and private uses, but also, particularly in the Western States, the ravages of veral groups of native ground squirrels and other noxious rodents grain and certain other field crops. Nor is this all, for it has

NOTE.—This bulletin, a joint contribution of the Bureau of Biological Survey and the zona Agricultural Experiment Station, contains a summary of the results of investigans of the relation of a subspecies of kangaroo rat to the carrying capacity of the open ges, being one phase of a general study of the life histories of rodent groups as they ect agriculture, forestry, and grazing.

been found that such rodents as prairie dogs, pocket gophers, marmots, ground squirrels, and rabbits take appreciable and serious toll of the forage on the open grazing range; in fact, that they reduce the carrying capacity of the range to such an extent that expenditures for control measures are amply justified. Current estimates place the loss of goods due to rats and mice in warehouses and stores throughout the United States at no less than $200,000,000 annually, and damage to the carrying capacity of the open range and to cultivated crops generally by native rodents in the Western States at $300,000,000 additional; added together, we have an impressive total from depredations of rodents.

The distribution and life habits of rodents and the general consideration of their relation to agriculture, forestry, and grazing, with special reference to the carrying capacity of stock ranges, is a subject that has received attention for many years from the Biological Survey of the United States Department of Agriculture. As a result of the investigations conducted much has been learned concerning the economic status of most of the more important groups, and the knowledge already gained forms the basis of the extensive rodent-control work already in progress, and in which many States are cooperating with the bureau. If the work is to be prosecuted intelligently and the fullest measure of success achieved, it is essential that the consideration largely of groups as a whole be supplemented by more exhaustive treatment of the life histories of individual species and of their place in the biological complex. The present report is based upon investigations, chiefly in Arizona, of the life history, habits, and economic status of the banner-tailed kangaroo rat, *Dipodomys spectabilis spectabilis* Merriam (Pl. I).

INVESTIGATIONAL METHODS.

Some 18 years ago (in 1903) a tract of land 49.2 square miles in area on the Coronado National Forest near the Santa Rita Mountains, Pima County, southern Arizona, was closed to grazing by arrangement between the Forest Service and the Agricultural Experiment Station of the University of Arizona. Since that time another small tract of nearly a section has been inclosed (Griffiths, 1910, 7[1]). This total area of approximately 50 square miles is known as the United States Range Reserve, and is being devoted to a study of grazing conditions in this section and to working out the best methods of administering the range (Pl. II, Fig. 1).

[1] References in parentheses are to the Bibliography, p. 40 (the last figure being to the page of the publication). References to authorities where no citation of literature is appended relate for the most part to manuscript notes in the files of the Biological Survey or the University of Arizona Agricultural Experiment Station.

For some years an intensive study of the forage and other vegetative conditions of this area has been made, the permanent vegetation quadrat, as proposed by Dr. F. E. Clements (1905, 161–175), being largely utilized. During the autumn of 1917 representatives of the Carnegie Institution and the Arizona Agricultural Experiment Station visited the Reserve and were impressed with the evidence of rodent damage to the grass cover. The most conspicuous appearance of damage was noted about the habitations of the banner-tailed kangaroo rat (*Dipodomys spectabilis spectabilis* Merriam), although it was observed also that jack rabbits of two species (*Lepus californicus eremicus* Allen and *L. alleni alleni* Mearns), which were very abundant in some portions of the reserve, were apparently affecting adversely the forage conditions in particular localities. Accordingly, the Biological Survey, the Agricultural Experiment Station of the University of Arizona, the Carnegie Institution of Washington, and the U. S. Forest Service have undertaken a study of the relation of the more important rodents to the forage crop of the Range Reserve in Arizona.

The present paper is a first step in this larger investigation.[2] In this work the authors have made no attempt to deal with the taxonomic side of the kangaroo rat problem. It is not unlikely that intensive studies will show that the form now known as *Dipodomys spectabilis spectabilis* is made up of a number of local variants, some of them perhaps worthy of recognition as additional subspecies. But it is felt that the conclusions here reached will be little, if at all, affected by such developments.

Color descriptions are based on Ridgway's Color Standards and Color Nomenclature published in 1912.

IDENTIFICATION.

There are only three groups of mammals in the Southwest having external cheek pouches. These are (*a*) the pocket gophers (Geomyidæ), which have strong fore feet, relatively weak hind feet, and short tail, as compared with weak fore feet, relatively strong hind feet, and long tail in the other two; (*b*) the pocket mice (*Perognathus*), which are considerably smaller than the kangaroo rats and

[2] In addition to assistance rendered by officials of the Biological Survey and the University of Arizona, which is hereby acknowledged, the authors are indebted to the following persons for helpful suggestions and assistance: G. S. Miller and J. W. Gidley, of the U. S. National Museum; Dr. Frederic E. Clements and Gorm Loftfield, of the Carnegie Institution; Morgan Hebard, of the Academy of Natural Sciences of Philadelphia; James T. Jardine and R. L. Hensel, both formerly connected with the U. S. Forest Service; and R. R. Hill, of the Forest Service. They are also indebted to William Nicholson, of Continental, Ariz., for many courtesies extended in connection with work on the Reserve.

lack the conspicuous white hip stripe possessed by all the latter; and (*c*) the kangaroo rats (*Dipodomys*).

Dipodomys spectabilis spectabilis Merriam requires comparison with three other forms of kangaroo rats in the same general region, namely, *D. deserti* Stephens, of approximately the same size, and *D. merriami* Mearns and *D. ordii* Woodhouse, the last two of decidedly smaller size. The range of *deserti* lies principally to the

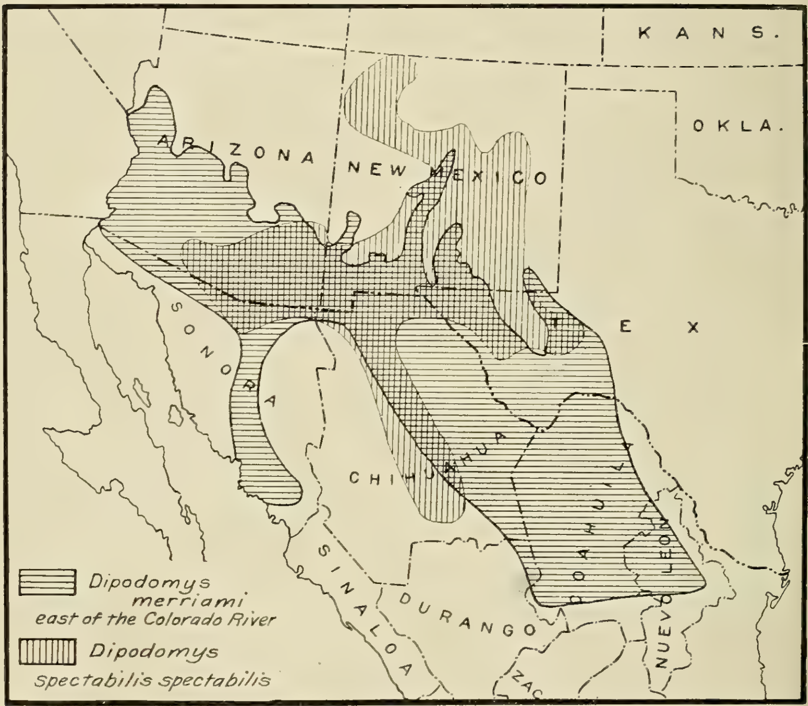

FIG. 1.—Range, east of the Colorado River, of *Dipodomys spectabilis spectabilis* compared with that of *Dipodomys merriami*. Cross hatching indicates area of overlapping of the two forms. The range of *Dipodomys deserti*, not shown on the map, is west of that of *spectabilis*, and so far as known the two do not overlap.

west of that of *spectabilis*, and the two do not, so far as known, overlap. On the other hand, *merriami* and *ordii*, and subspecies, occur over a large part of the range of *spectabilis*, living in very close proximity to its burrows; *merriami* is even suspected of pillaging the stores of *spectabilis*. The range of *merriami*, however, is much more extensive than that of *spectabilis* (Fig. 1), which argues against a definite ecological dependence or relationship. Separation of the four forms mentioned may be easily accomplished by the following key:

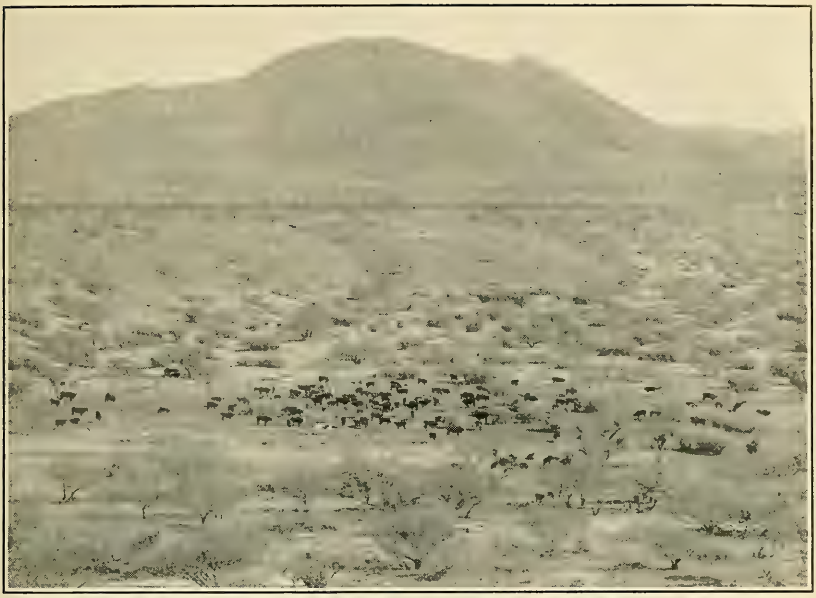

FIG. 1.—WINTER VIEW OF AREA INHABITED BY KANGAROO RATS.

A water-hole scene on the U. S. Range Reserve at the base of the Santa Rita Mountains, Ariz., where cooperative investigations are being conducted to ascertain the relation of rodents to forage. This is typical of a large section of country occupied by *Dipodomys spectabilis spectabilis* and *Dipodomys merriami*. The brush is mesquite (*Prosopis*), cat's-claw (*Acacia*), and paloverde (*Cercidium*).

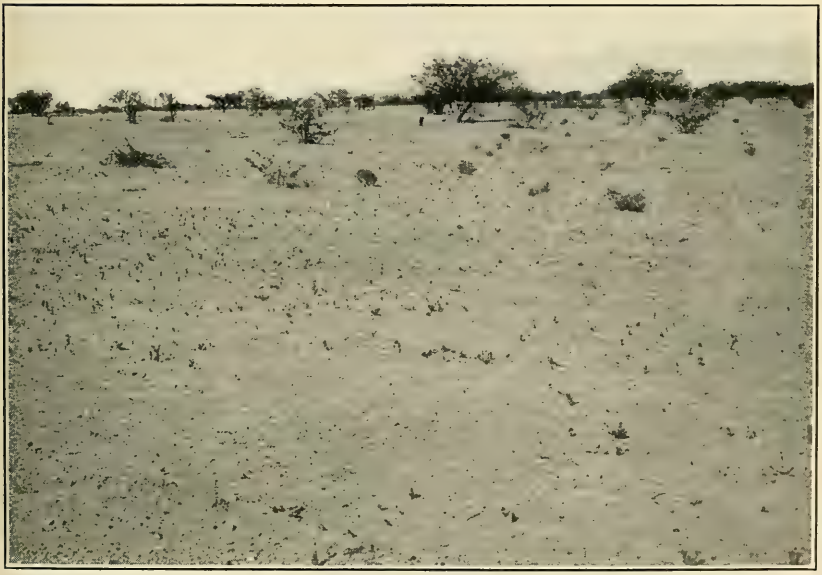

FIG. 2.—KANGAROO RAT COUNTRY FOLLOWING SUMMER DROUGHT.

An area of the U. S. Range Reserve in the autumn of 1918, showing the result of failure of summer rains. Such a condition is critical not only for the stockmen but also for kangaroo rats and other desert rodents, and results in competition between them as to which shall benefit by what the range has to offer.

FIG. 1.—KANGAROO RAT MOUND (DIPODOMYS S. SPECTABILIS).

Typical *Dipodomys s. spectabilis* mound on the Range Reserve, under shelter of desert hackberry (*Celtis pallida*). Most dens on the reserve are located in the shelter of brush plants, the more important being mesquite (*Prosopis velutina*), cat's-claw (*Acacia* spp.), and the desert hackberry. (See also Pl. VIII Fig. 2.)

FIG. 2.—KANGAROO RAT MOUND (DIPODOMYS DESERTI).

Den of *Dipodomys deserti deserti*, showing typical wide, low mound with numerous entrance holes. This species excavates its den in soft, sandy soil. The tree is a species of *Dalea*.

Key to Species of Dipodomys *in Arizona.*

a^1. Size much larger (hind foot and greatest length of skull more than 42 millimeters); tail tipped with white.

b^1. Upper parts dark brownish buffy; tail dark brownish or blackish with more sharply contrasted white tip; interparietal broader, distinctly separating mastoids (range in Arizona mainly southeastern part) ---------- **Dipodomys spectabilis.**

b^2. Upper parts light ochraceous-buffy; tail pale brownish with less sharply contrasted white tip; interparietal narrower, reduced to mere spicule between mastoids (range in Arizona mainly southwestern part) ---------- **Dipodomys deserti.**

a^2. Size much smaller (hind foot and greatest length of skull less than 42 millimeters); tail not tipped with white.

b^1. Hind foot with four toes ---------- **Dipodomys merriami.**

b^2. Hind foot with five toes ---------- **Dipodomys ordii.**

On account of the small size, *merriami* and *ordii* do not require detailed color comparison with the other two. The general color of the upperparts of *spectabilis* is much darker than that of *deserti;* whereas *spectabilis* is ochraceous-buff or light ochraceous-buff grizzled with blackish, *deserti* is near pale ochraceous-buff and lacks the blackish.

The color of the upperparts alone amply suffices to distinguish *spectabilis* and *deserti;* but the different coloration of the tail is the most obvious diagnostic feature. The near black of the middle portion of the tail, the conspicuous white side stripes, and the pure white tip make the tail of *spectabilis* stand in rather vivid contrast to the pale-brown and whitish tail of *deserti.*

The dens of the two larger species of *Dipodomys—spectabilis* and *deserti*—can be distinguished at a glance from those of the two smaller—*merriami* and *ordii*—by the fact that the mounds of the former are usually of considerable size and the burrow mouths are of greater diameter. On the Range Reserve *merriami* erects no mounds, but excavates its burrows in the open or at the base of *Prosopis*, *Lycium*, or other brush. The mounds of *spectabilis* are higher than those of *deserti*, the entrances are larger, and they are located in harder soil (Pl. III, Fig. 1). The dens of *deserti* are usually more extensive in surface area than those of *spectabilis*, and have a greater number of openings (Pl. III, Fig. 2).

DESCRIPTION.

GENERAL CHARACTERS.

Size large; ears moderate, ear from crown (taken in dry skin) 9 or 10 millimeters; eyes prominent; whiskers long and sensitive; fore feet short and weak; hind feet long and powerful, provided with four well-developed toes; tail very long, usually 30 to 40 per cent

longer than the body. Cranium triangular, the occiput forming the base and the point of the nose the apex of the triangle, much flattened, auditory and particularly mastoid bullae conspicuously inflated.

COLOR.

General color above, brownish buffy, varying in some specimens to lighter buffy tints, grizzled with black; oblique hip stripes white; tail with dark-brown or blackish stripes above and below, running into blackish about halfway between base and tip, and with two lateral side stripes of white to a point about halfway back; tail tipped with pure white for about 40 millimeters (Pl. I). Underparts white, hairs white to bases, with some plumbeous and buffy hairs about base of tail; fore legs and fore feet white all around; hind legs like back, brown above, hairs with gray bases, becoming blackish (fuscous-black or chætura-black) about ankles, hairs on under side white to bases; hind feet white above, dark-brown or blackish (near fuscous) below.

Color variations in a series of 12 specimens from the type locality and points widely scattered through the range of *spectabilis* consist in minor modifications of the degree of coloration, length of white tip of tail, and length of white lateral tail stripes. In general the color pattern and characters are remarkably uniform. Young specimens, while exhibiting the color pattern and general color of adults are conspicuously less brown, and more grayish.

There appears to be little variation in color with season. In the series at hand, most specimens taken during the fall, winter, and spring are very slightly browner than those of summer, suggesting that the fresh pelage following the fall molt is a little brighter than is the pelage after being worn all winter and into the following summer. But at most the difference is slight.

OIL GLAND.

Upon separating the hairs of the middle region of the back about a third of the distance between the ears and the rump, one uncovers a prominent gland, elliptical in outline, with long axis longitudinal and about 9 millimeters in length. The gland presents a roughened and granular appearance, and fewer hairs grow upon it than elsewhere on the back. The hairs in the vicinity are frequently matted, as if with a secretion. In worn stage of pelage the gland may be visible from above without separating the hairs. Bailey has suggested that this functions as an oil gland for dressing the fur, and our observations bear out this view. Kangaroo rats kept in captivity without earth or sand soon come to have a bedraggled appearance, as if the pelage were moist. When supplied with fine

dusty sand, they soon recover their normal sleek appearance. Apparently the former condition is due to an excess of oil, the latter to the absorption of the excess in a dust bath. The oil is doubtless an important adjunct to the preservation of the skin and hair amid the dusty surroundings in which the animal lives.

MEASUREMENTS AND WEIGHTS.

External measurements include: *Total length*, from tip of nose

ERRATUM.

Page 7. Change first line of third paragraph under "Measurements and weights," to read—

Average measurements of 30 adult specimens of both sexes:

(The first line of the succeeding paragraph is correct.)

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averaged 112.9 grams (131.9–98.0).

Averages for 13 adult males: Total length, 326 millimeters (345–311); tail vertebræ, 187.8 (202–168); weight, 116.8 grams (129–100).

There appears to be no significant difference in the measurements and weights of males and females, with the possible exception of the comparison of adult males and adult nonpregnant females.

OCCURRENCE.

GENERAL DISTRIBUTION.

Dipodomys spectabilis spectabilis is found in southeastern Arizona, in northwestern, central, and southern New Mexico, in extreme western Texas, in northern Sonora, and in northern and central Chihuahua (Fig. 1). A subspecies, *D. s. cratodon* Merriam, has been described from Chicalote, Aguas Calientes, Mexico, the geographic range of which lies in central Mexico in portions of the States of Zacatecas, San Luis Potosi, and Aguas Calientes.

HABITAT.

In the Tucson region *spectabilis* is typically a resident of the Lower Sonoran Zone. This is perhaps the principal zone inhabited over its entire range, but the animal is often found in the Upper Sonoran also, and in the Gallina Mountains of New Mexico Hollister found it

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MEASUREMENTS AND WEIGHTS.

External measurements include: *Total length*, from tip of nose to tip of tail without hairs, measured before skinning; *tail vertebræ*, length of tail from point in angle when tail is bent at right angles to body to tip of tail without hairs; and *hind foot*, from heel to tip of longest claw.

The following are measurements of a series from the U. S. Range Reserve:

Averages for 17 adult females: Total length, 326.4 millimeters Total length, 326.2 millimeters (349–310); tail vertebræ, 188.4 (208–180); hind foot, 49.5 (51–47); the average weight of 29 adult specimens of both sexes was 114.5 grams (131.9–98.0).

Averages for 17 adult females: Total length, 326.4 millimeters (349–310); tail vertebræ, 188.8 (208–179); weight (16 individuals), 113.7 (131.9–98.0); excluding pregnant females, 13 individuals averaged 112.9 grams (131.9–98.0).

Averages for 13 adult males: Total length, 326 millimeters (345–311); tail vertebræ, 187.8 (202–168); weight, 116.8 grams (129–100).

There appears to be no significant difference in the measurements and weights of males and females, with the possible exception of the comparison of adult males and adult nonpregnant females.

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invading the yellow pine Transition where the soil was dry and sandy and the pine woods of open character. The same observer found it common in grassy and weed-grown parks among the large junipers, pinyons, and scattering yellow pines of the Bear Spring Mountains, N. Mex. Bailey calls attention to the fact that the animal apparently does not inhabit the lower half of the Lower Sonoran Zone, as it extends neither into the Rio Grande Valley of Texas nor the Gila Valley of Arizona. In extreme western Texas it is common at the upper edge of the arid Lower Sonoran Zone, and in this region does not enter the Upper Sonoran to any extent.

In July, 1914, Goldman found this kangaroo rat common on the plain at 4,600 feet altitude, near Bonita, Graham County, Ariz., and noted a few as high as 5,000 feet altitude on the warm southwestern slopes of the Graham Mountains, near Fort Grant. Apparently *spectabilis* reaches its upper altitude limit in the Burro Mountains, N. Mex., where Bailey has found it sparingly on warm slopes up to 5,700 feet, and at the western base of the Sandia Mountains, east of Albuquerque, N. Mex., where dens occur at approximately 6,000 feet.

About Tucson it is undoubtedly more common in the somewhat higher portions of the Lower Sonoran Zone, above the *Covillea* association, than elsewhere (Pl. IV, Figs. 1 and 2). A few scattered dens are to be seen in the *Covillea* belt, but as one rises to altitudes of 3,500 to 4,000 feet, and the *Covillea* is replaced by the cat's-claws (*Acacia* sp. and *Mimosa* sp.) and scattered mesquite (*Prosopis*), with the *Opuntia* becoming less abundant, kangaroo rat mounds come more and more in evidence. Here is to be found the principal grass growth supporting the grazing industry, and the presence of a more luxuriant grass flora is probably an important factor in the greater abundance of kangaroo rats, both *spectabilis* and *merriami*. In this generally preferred environment the desert hackberry (*Celtis pallida*) is one of the most conspicuous shrubs; clumps of this species are commonly accompanied by kangaroo rat mounds.

In order to ascertain whether the banner-tailed kangaroo rat has any marked preference for building its mounds under *Celtis* or some other particular plant, all the observable mounds were counted in a strip about 20 rods wide and approximately 4 miles long, an area of approximately 160 acres, particular note being taken of the kind of shrub under which each mound was located. Of 300 mounds in this area, 96 were under *Prosopis*, 95 under *Acacia*, 65 under *Celtis*, 11 under *Lycium*, 31 in the open, 1 about a "cholla" cactus (*Opuntia spinosior*), and 1 about a prickly pear (*Opuntia* sp.). There is apparently no strongly marked preference for any single species of plant. While both desert hackberry and the cat's-claws afford a better

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FIG. 1.—RANGE CONDITIONS FAVORING KANGAROO RATS.

View on higher portion of Range Reserve, showing type of country where *Dipodomys s. spectabilis* is most abundant. Good growth of grama and needle grasses in October, following summer growth and before grazing off by cattle and rodents.

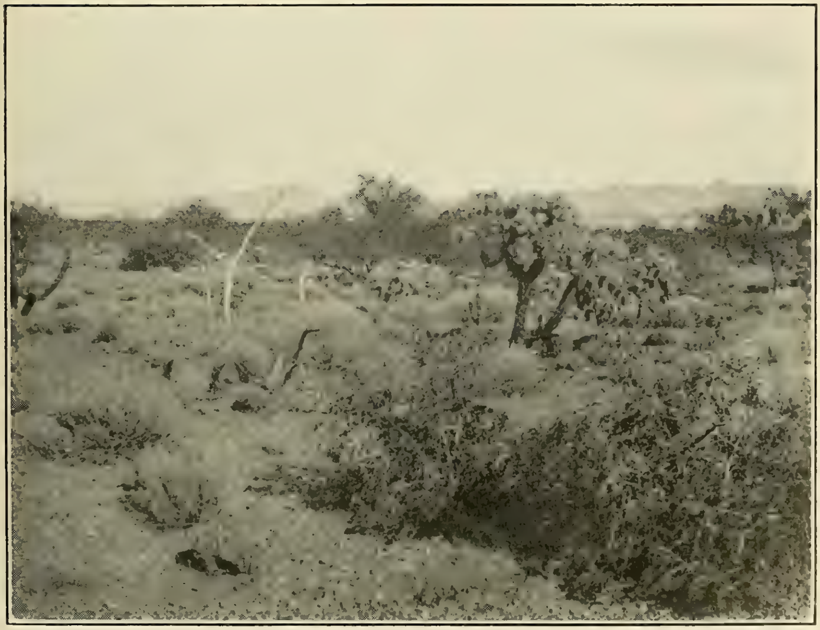

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FIG. 2.—RANGE CONDITIONS LESS FAVORABLE TO KANGAROO RATS.

View on lower portion of Range Reserve, where *Dipodomys s. spectabilis* is less abundant. Vegetation consists principally of *Lycium*, mesquite, rabbit brush, and cactus, there being very little grass.

protection than mesquite—since cattle more often seek shade under the latter, and in so doing frequently trample the mounds severely—it appears that the general protection of a tree or shrub of some sort is sought by kangaroo rats, rather than the specific protection of the thickest or thorniest species.

The following records indicate particular habitat preferences of *spectabilis* as noted at different points in its range:

Occurs on open bare knolls exposed to winds, also on gravelly places at lower edge of foothills (Franklin Mountains, Tex., Gaut); here and there over the barest and hardest of the gravelly mesas (Bailey, Tex., 1905, 147); on open creosote-bush and giant-cactus desert (Tucson, Ariz., Vorhies and Taylor); on firm, gravelly, or even rocky soil on the grassy bajada land along the northwest base of the mountains, either in the open or under *Celtis, Prosopis, Lycium, Acacia greggii*, or other brush (Santa Rita Mountains, Ariz., Vorhies and Taylor); mounds usually thrown up around a bunch of cactus or mesquite brush (Magdalena, Sonora, Bailey); in heavy soil (Ajo, Ariz., A. B. Howell); loamy soil (Gunsight, Ariz., A. B. Howell); in mesa where not too stony (Magdalena, Sonora, Bailey); grassy plain (Gallego, Chihuahua, Nelson); in open valley and high open plains (Santa Rosa, N. Mex., Bailey); in grassy and weed-grown parks among the larger junipers, pinyons, and scattering yellow pines (Bear Spring Mountains, N. Mex., Hollister); on sand-dune strip (east side of Pecos River, 15 miles northeast of Roswell, N. Mex., Bailey); among *Ephedra* patches (San Juan Valley, N. Mex., Birdseye); in open sandy soil along dry wash (Rio Alamosa, N. Mex., Goldman); on sides and crests of bare, stony hills (Mesa Jumanes, N. Mex., Gaut); in open, arid part of the valley and stony mesas (Carlsbad and Pecos Valley, N. Mex., Bailey); about the edges of the plains of San Augustine and the foothills of the Datil and Gallina Mountains, and in the Transition Zone yellow-pine forest of the Gallina Mountains (Datil region, N. Mex., Hollister); on hard limy ridges (Monahans, Tex., Cary).

A. Brazier Howell notes that *spectabilis* occurs in harder soil than does *deserti*. This observation is confirmed by others, and seems to afford a conspicuous habitat difference between the two, for *deserti* is typically an animal of the shifting aeolian sands.

Usually, as on the Range Reserve, the rodents are widely distributed over a considerable area. Occasionally, as in the vicinity of Rio Alamosa, N. Mex., as reported by Goldman, they occur only in small colonies.

HABITS.

EVIDENCE OF PRESENCE.

MOUNDS.

One traveling over territory thickly occupied by the banner-tailed kangaroo rat is certain to note the numerous and conspicuous mounds so characteristic of the species, particularly if the region is of the savannah type, grassy rather than brushy. These low, rounded mounds occupy an area of several feet in diameter, and rise to vary-

ing heights above the general surface of the surrounding soil, the height depending rather more upon the character of the soil and the location of the mound as to exposure or protection than upon the area occupied by the burrow system which lies within and is the reason for the mound.

A den in sandy soil in the open may be of maximum size in area occupied and yet scarcely present the appearance of a mound in any sense, due probably both to the fact that the sandy soil will not heap up to such a height over a honeycomb of tunnels as will a firmer or rocky soil, and also to its greater exposure to the leveling action of rains and the trampling of animals. These mounds are in themselves large enough to attract some attention, but their conspicuousness is enhanced by the fact that they are more or less completely denuded of vegetation and are the centers of cleared areas often as much as 30 feet in diameter (Pl. V, Fig. 1); and further that from 3 to 12 large dark openings loom up in every mound. The larger openings are of such size as to suggest the presence of a much larger animal than actually inhabits the mound. Add to the above the fact that the traveler by day never sees the mound builder, and we have the chief reasons why curiosity is so often aroused by these habitations.

On the Range Reserve the mounds are usually rendered conspicuous by the absence of small vegetation, but Nelson writes that in the vicinity of Gallego, Chihuahua, they can be readily distinguished at a distance because of a growth of weeds and small bushes over their summits, which overtop the grass. In the vicinity of Albuquerque, N. Mex., Bailey reports (and this was recently confirmed by Vorhies) that the mounds about the holes of *spectabilis* are often hardly noticeable. Hollister writes that in the yellow-pine forests of the Gallina Mountains the burrows are usually under the trunk of some fallen pine, both sides of it in some cases being taken up with holes, there being some eight or ten entrances along each side, the burrows extending into the ground beneath the log. In the vicinity of Blanco, N. Mex., Birdseye says that occasionally *spectabilis* makes typical dens but more often lives in old prairie-dog holes (*Cynomys*), or in holes which look more like those of *D. ordii*.

Runways and Tracks.

Still other features add to the interest in the dwelling places of *spectabilis*. Radiating in various directions from some of the openings of the mounds well-used runways are to be seen, some of them fading out in the surrounding vegetation, but others extending 30, 40, or even 50 or more yards to neighboring burrows or mounds (Pl. V, Fig. 2; Pl. VI, Fig. 1). These runways and the entrances to the mounds are well worn, showing that the inhabitants are at home and

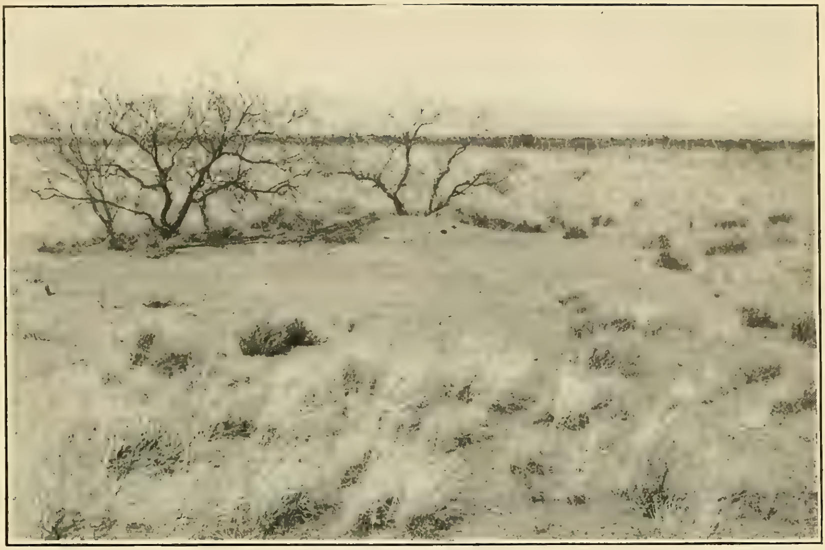

FIG. 1.—CLEARING ABOUT A MOUND.

A typica :clearing about a mound of *Dipodomys s. spectabilis*, showing the autumnal denudation of the mound and surrounding areas .in this instance about 30 feet in diameter.

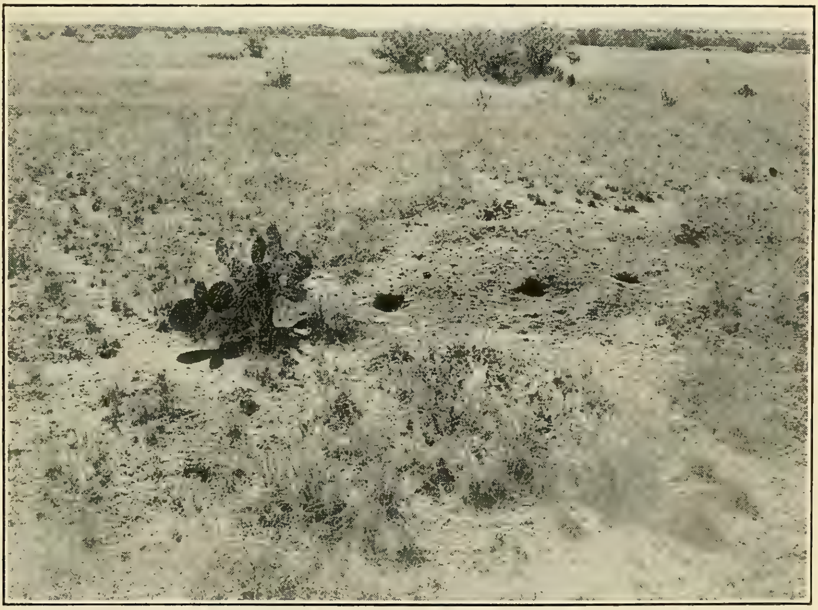

FIG. 2.—MOUND AND RUNWAYS.

A small mound of *Dipodomys s. spectabilis* in early autumn, showing runways radiating from the den. Evidences of activity may be noted in and about the surface of the mound.

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FIG. 1.—RUNWAY OF DIPODOMYS S. SPECTABILIS.

Well-traveled path leading from the main den, in the foreground, to a subsidiary burrow (see Fig. 2, below), about 30 feet distant, at apparent end of runway.

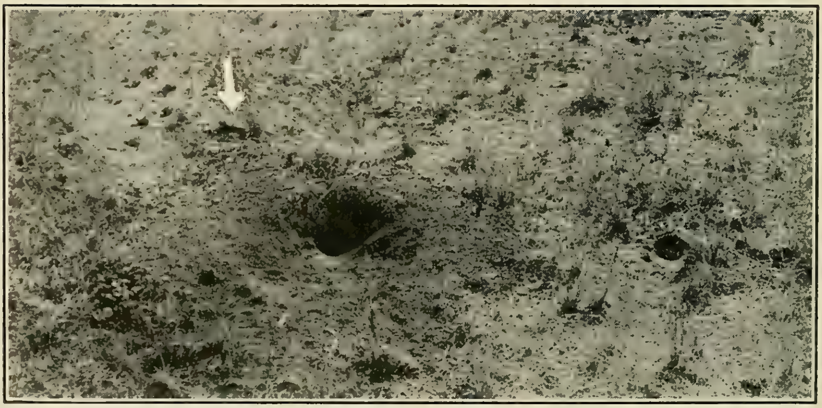

FIG. 2.—SUBSIDIARY BURROW OF DIPODOMYS S. SPECTABILIS.

Located at the end of the 30-foot runway shown in Figure 1, above. This has three openings, two in the foreground and the third a little to the rear and indicated by an arrow.

are at some time of day very active. The worn paths become most conspicuous in the autumnal harvest season, when they stand out in strong contrast to surrounding grass. One usually finds not far distant from the main habitation one or more smaller burrows, each with from one to three typical openings, connected by the trail or runway system with the central den, and these we have called "subsidiary burrows" (Pl. VI, Fig. 2). These will be again referred to in discussing the detailed plan of the entire shelter system.

Examination of the runways and of the denuded area about a mound discloses an abundance of almost indecipherable tracks. The dust or sand is ordinarily much too dry and shifting to record clear footprints, and there are no opportunities to see footprints of this species recorded in good impressionable soil. Very characteristic traces of kangaroo rats may be readily observed in the dust about the mounds, however, and these are long, narrow, sometimes curving, furrows made by the long tails as the animals whisk about their work or play.

Signals.

If a scratching or tapping sound be made at the mouth of a burrow, even in the daytime, one is likely to hear a muffled tapping in response, and this may at times be heard while one is engaged in excavating a mound. It has a chirring or fluttering quality, described by Fisher as resembling the noise of a quail flying. Bailey (1905, 148) is of the opinion that it is used as a signal of alarm, call note, or challenge, a view which the present authors believe to be correct. During the winter of 1920–21, however, both Bailey and Vorhies discovered that this sound, or a very similar one, is made by the rapid action of the forefeet in digging. On one occasion in the laboratory the sound was given by one of a pair and was responded to at once by the other, the two being in separate but contiguous cages. This observation, however, could not be repeated. (Vorhies MS.)

One evening, while working in the vicinity of the Burro Mountains, N. Mex., Goldman heard a kangaroo rat near camp making this thumping noise. Taking a lantern, he approached the den, very cautiously, until within 10 feet. The kangaroo rat was just outside the entrance of one of its burrows, and though moving about more or less restlessly at first showed little fear, and kept up the thumping or drumming at intervals. When making the noise the animal was standing with the forefeet on the ground and the tail lying extended. The noise seemed to be made with the hind feet only, and the vibration of the feet could be seen. The tapping was kept up for a second or two at a time, the sounds coming close together and being repeated

rhythmically after a very short interval, suggesting the distant galloping of a horse. After continuing in this way for a short time, the animal turned quickly about, with its head in the opposite direction, and began tapping. It appeared to pay little attention to the light, but finally gave a sudden bound and entered one of its holes about 4 feet from the one in front of which it had been standing.

Vorhies has repeatedly noted when watching for the appearance of a kangaroo rat at night that this sound invariably precedes the rodent's first emergence into the open, and often its appearance after an alarm, though when the storage season has begun and the kangaroo rat is carrying loads of grass heads or other material into its den, it regularly comes out without preliminary signaling. Vorhies has also observed it making the sound while on top of the mound, and certainly not digging, but was unable to see how it was made.

Voice.

No data concerning any call notes or sounds other than those described above are at hand, with the following exception: Price (in Allen, 1895, 213), who studied the habits of the animal in the moonlight, at Willcox, Ariz., says that a low chuckle was uttered at intervals; and Vorhies has had one captive female that would repeatedly utter a similar chuckle in a peevish manner when disturbed by day, and one captive male which, when teased into a state of anger and excitement, would squeal much like a cornered house rat. Vorhies has spent many moonlight hours observing kangaroo rats, but without ever hearing a vocal sound uttered by free individuals.

DAILY AND SEASONAL ACTIVITY.

The kangaroo rat is strictly nocturnal. An observer watching patiently by a den in the evening for the animal's first appearance is not rewarded until darkness has fallen completely, and unless the moon is shining the animal can hardly be seen. Were it not for the white tail-brush of *spectabilis* and its white belly when upright on the hind legs and tail, one could not as a rule see the animal at all when it makes its first evening appearance. With the first streak of dawn activity usually ceases completely and much more abruptly than it began with the coming of darkness, but on a recent occasion Vorhies observed that a kangaroo rat which did not appear until near morning remained above ground until quite light, but not fully daylight. On removal of the plug from the mouth of a kangaroo rat burrow, one may sometimes see a fresh mass of earth and refuse shoved into the opening from within. As often as not, however, even this unwelcome attention does not elicit any response by day, the great majority of the burrow openings of this species, as observed by the authors, remaining permanently open.

The ordinary activities of the kangaroo rat in southern Arizona can scarcely be said to show any true seasonal variation. The animals are active all the year in this region, there being neither hibernation nor estivation, both perhaps being rendered unnecessary by the storage habit, to be discussed in full later (pp. 15–16), and by the mildness of the winter climate. On any particular night that the weather is rainy, or the ground too wet and cold, activity is confined to the interior of the burrow system, and for this reason one has no opportunity to see a perfect imprint of the foot in freshly wet soil or in snow. On two or three of the comparatively rare occasions on which there was a light fall of snow on the Range Reserve a search was made for tracks in the snow. At these times, however, as on rainy nights, the only signs of activity were the pushing or throwing out of fresh earth and food refuse from within the burrow. This is so common a sight as to be complete evidence that the animals are active within their dens during stormy weather but do not venture outside. Trapping has again and again proved to be useless on rainy nights, unless the rain is scant and a part of the night favorable, in which case occasional individuals are taken. These statements apply to the Range Reserve particularly; the facts may be quite different where the animals experience more winter, as at Albuquerque, N. Mex., although in November, 1921, Vorhies noted no indications of lessened activity in that region.

PUGNACITY AND SOCIABILITY.

So far as their reactions toward man are concerned, kangaroo rats are gentle and make confiding and interesting pets; this is especially the case with *merriami*. This characteristic is the more surprising in view of the fact that they will fight each other so readily and so viciously, and yet probably it is explained in part by their method of fighting. They do not appear to use their teeth toward each other, but fight by leaping in the air and striking with the powerful hind feet, reminding one most forcibly of a pair of game cocks, facing each other and guarding in the same manner. Sometimes they carry on a sparring match with their fore feet. Biting, if done at all, is only a secondary means of combat. When taken in hand, even for the first time, they will use their teeth only in the event that they are wounded. The jaws are not powerful, and though the animals may lay hold of a bare finger, with the apparent intention of biting, usually they do not succeed in drawing blood. As Bailey says (1905, 148), they are gentle and timid, and, like rabbits, depend upon flight and their burrows for protection.

The well-traveled trails elsewhere described (p. 10) indicate a degree of sociability difficult to explain in connection with their pug-

nacity toward each other. While three or four individuals may sometimes be trapped at a single mound, more than two are seldom so caught, and most often only one in one night. Trapping on successive nights at one mound often yields the larger number, yet in some cases the number is explained by the fact that two or three nearly mature young are taken, and the capture of several individuals at a single mound can not be taken to indicate that all are from the one den. Our investigations tend strongly to the conclusion that only one adult occupies a mound, except during the period when the young are in the parental (or maternal) den. In the gassing and excavating of 25 or more mounds we have never found more than one animal in a den, except in one instance, and then the two present were obviously young animals.

SENSE DEVELOPMENTS.

Without making special investigations through a study of behavior or other special methods, one can speak in only general terms regarding what appear to be the special sense developments of kangaroo rats. The eyes are large, as is very often the case in nocturnal animals, and when brought out into the bright light of day the rats perhaps do not see well. Yet, if an animal leaves a den which is in process of excavation, and follows one runway, even in bright sunlight, it makes excellent speed to the next opening, often a distance of several yards. Whether this is accomplished chiefly by the aid of sight or in large measure by a maze-following ability, such as experiments have shown some rodents to have, can not be stated without precise experimentation. Marked ability to follow a maze would not be at all surprising in view of the labyrinthine character of the underground passages which make up the normal habitation.

When watching beside a mound by moonlight one is impressed with the fact that the rats possess either a very keen sense of hearing or of sight, probably both. The very slightest movement or noise on the part of the observer results, with a timid individual, in an instantaneous leap for safety, a disappearance into the burrow so sudden as to be almost startling. All attempts to obtain flashlight photographs at the mounds were failures, the animal either having gotten completely out of the field before the light flashed following the pull of the trigger, or leaving merely an indistinguishable blur on the plate as it went, and this in spite of carefully hiding the trigger chain behind a screen. A slight noise accompanying the trigger action gave the alarm in one case, and in another the length of time of the flash was sufficient for the get-away. The marvelous quickness of the animal clearly indicates a remarkably short reaction time.

Occasionally a bold individual is found, as in the case of one which came out repeatedly, even after being flashed twice in the same night.

Certain peculiar physical characteristics suggest a relationship to sense reactions. On these, however, the authors are not prepared to do more than offer suggestions for future work. The extremely large mastoids found in kangaroo rats suggest a connection in some way with special developments of the sense of hearing or of balance. It may be noted that an intermediate condition between the kangaroo rats and the majority of rodents in respect to this character is to be found in the pocket mice (*Perognathus*), which belong to the same family. Herein lies a field for some interesting experimentation and discovery.

The small, pointed nose might suggest a not overkeen sense of smell, and there appears no reason to believe that this sense is particularly well developed. However, the turbinals are very complex. The vibrissæ are long and sensitive, and may indicate a special development of the sense of touch as an adaptation to nocturnal habits and to life in an underground labyrinth. The long, well-haired tail doubtless serves as an important tactile organ as well as a balance.

MOVEMENTS AND ATTITUDES.

Movements and attitudes are characteristic. As a kangaroo rat emerges from the burrow a reason for the relatively large size of the opening is seen in the fact that, kangaroolike, the animal maintains a partially upright position. Its ordinary mode of progression is hopping along on the large hind legs, or, when in the open and going at speed, leaping. When moving slowly about over the mound, as if searching for food, it uses the fore legs in a kind of creeping movement. It appears to be creeping when pocketing grain strewn about, but close observation shows that the fore feet are then used for sweeping material into the pockets, reminding one somewhat of a vacuum cleaner. When it assumes a partially upright position the fore limbs are usually drawn up so closely that they can be seen only by looking upward from a somewhat lower level than that occupied by the animal. The slower movements of searching or playing about the mound are occasionally interrupted by a sudden leap directly upward to a height of $1\frac{1}{2}$ to 2 feet, often with no apparent reason other than play. This is, however, a fighting or guarding movement, though indulged in for play. The play instinct seems to be well developed, and in evidence on any moonlight night when actual harvesting operations are not going on.

STORING HABITS.

Probably no instinct is of greater importance to the kangaroo rat than that of storing food supplies. When a crop of desirable seeds

is maturing the animal's activities appear to be concentrated on this work. During September, 1919, when a good crop of grass seed was ripening following the summer rains, a kangaroo rat under observation made repeated round trips to the harvest field of grass heads. Each outward trip occupied from 1 to 1½ minutes, while the unloading trip into the burrow took only 15 to 20 seconds.

One individual in a laboratory cage, which had not yet been given a nest box, busied itself in broad daylight in carrying its grain supply into the darkest corner of the cage. When a nest box is supplied the individual will retreat into its dark shelter, and will only come forth after darkness has fallen unless forcibly ejected, but will store the food supplied.

In another case an animal escaped while being handled, and sought refuge behind a built-in laboratory table, where it could not be recovered without tearing out the table. For four days and nights it had the run of the laboratory. On the first night of its freedom it found and entered a burlap bag of grass seed that had been taken from a mound. A trail of seed and chaff next morning showed that it had been busily engaged in making its new quarters comfortable with bedding and food. After four nights of freedom it was captured alive in a trap, and later it was found that it had moved from the corner behind the table to the space beneath a near-by drawer, where it had stored about 2 quarts of the grass seed and a handful of the oatmeal used for trap bait.

BREEDING HABITS.

Observations on breeding habits have consisted mainly in taking records from the females trapped at all seasons of the year throughout the course of the investigation, and from examinations made during poisoning operations, and yet from this source the number of pregnant females taken or of young discovered is disappointingly small. The records indicate a breeding period of considerable length, extending from January to August, inclusive. It is possible that the length of the period may be increased by a second litter from the earliest breeding females in summer, but the large percentage of nonpregnant or nonbreeding animals which occurs throughout the season would indicate a wide variation in the time of breeding of different individuals.

Trapping in February and March for the purpose of securing greater numbers of female specimens, begun with the idea that these months were most likely to be the breeding months, has invariably yielded an unsatisfactory number of nonbreeding specimens and males. Unfortunately, the numbers of females secured in some months were not sufficient to be significant if worked out in per-

centages of breeding and nonbreeding individuals, and this, coupled with the fact that the importance of recording carefully all nonbreeders was not at first recognized, makes it impossible to tabulate such information reliably. The total of females taken in April, for example, is only 3, of which 1 was breeding; while in June, during the course of poisoning operations, 45 females were examined, of which 21 were breeding.

Five breeding females were taken in January, all during the last three days of the month. One of these was a suckling female, the young of which were secured alive and were probably at least a week old when taken. This must have been exceptionally early for young, since of a number of adult kangaroo rats taken during the first week of January none have been found to be breeding. Two records from Vernon Bailey are as follows: May 19–June 8, 1903, young specimen in nest (Santa Rosa, N. Mex.); June 12, 1889, one female, two embryos (Oracle, Ariz.).

The considerable proportion (which we believe to be more than 50 per cent) of nonbreeding females taken during all those months in which breeding has been found to occur may also indicate an extended period of breeding, with a small percentage breeding at any one time. This period also furnishes ample time for the rearing of two litters a year by some females, but we have no evidence as to the occurrence of two litters. Young of the year, practically grown, are taken during and after the month of April.

The mammae are arranged in three pairs, pectoral, $\frac{1}{1}$; inguinal, $\frac{2}{2}$. Kangaroo rats are among those rodents in which the vagina becomes plugged with a rather solid material, translucent, and of the consistency of a stiff gelatine, after copulation. This must occur very soon after coitus, since in those individuals taken in this condition no definite evidence of the beginning of development of embryos could be detected by examination.

The length of the gestation period of *spectabilis* is unknown. The young are born naked, a fact inferred by failure to find any fetus showing noticeable hair development, and from the conditions observed in such young as have been seen. A suckling female was taken by Vorhies, January 31, 1920, and her den immediately excavated in the hope of securing the young. Two juveniles were found in a special nest chamber (see p. 30). These were estimated to be perhaps two weeks old. A serious effort was made to raise the little animals by feeding milk with a pipette and keeping them warm with a hot water bottle, but they survived only 10 days, without the eyes having opened. The uneven temperature as well as the character of the food was probably responsible for their deaths. On February 3 they were measured and weighed, with the following results:

	Weight (in grams).	Measurements (in millimeters).		
		Total length.	Tail vertebrae.	Hind foot.
No. 1	13.3	90	38	24
No. 2	12.6	93	38	24

At this stage the young were partially clothed with a coat of fine velvety fur, more especially on the bodies, the tails being still nearly naked. The body color was dark plumbeous, just the color of the dark underfur of the adult, or a shade darker, while the characteristic white markings of the adult stood out sharply as pinkish-white areas against the dark background (see Pl. IX, Fig. 2, at p. 32). The proportions were much as in the adult, except that the tails were relatively much shorter and the feet relatively longer.

Only one other record of young is at hand, that by Bailey, who secured the young after capture of a suckling female at Santa Rosa, N. Mex. In this case the litter contained only one. This was squeaking when found, but was not large enough to crawl away. Its eyes and ears were closed, and its soft, naked skin was distinctly marked with the pattern of the adult, the colors being as given for the other two. This juvenile lived only a week. Young less than half grown were not trapped or noted in our poisoning operations outside the dens.

Kangaroo rats, if *spectabilis* be representative, reproduce at a slow rate as compared with many other small rodents. We have records of 67 females with embryos or scars showing the number produced, and of the two litters of young described above. Of the 69 females thus recorded, 15, or 21.7 per cent, had but one offspring each; 52, or 75.3 per cent, but two each; while only 2 individuals, or 2.9 per cent, had three. Three young is the maximum litter recorded. This, taken in connection with the protracted breeding season and lack of sure evidence of the production of two broods a year, gives a surprisingly low rate of reproduction, indicating relative freedom from inimical factors.

Our breeding records for *merriami* are fewer than for *spectabilis*, but are very similar in every way so far as they go, both as to the time of year and number of young.

FOOD AND STORAGE.

Dipodomys s. spectabilis does not hibernate, so must prepare for unfavorable seasons by extensive storage of food materials. There are two seasons of the year, in southeastern Arizona at least, when storage of food takes place, namely, in spring, during April or May, and in fall, from September to November, the latter being the more important. For the periods between, the animal must rely largely

on stored materials. Not infrequently a season of severe drought precludes the possibility of any storage. The summer and fall of 1918 was such a season on the Range Reserve (Pl. II, Fig. 2). If food stores are inadequate at such a time the kangaroo rats must perish in considerable numbers. Fisher found many deserted mounds in the vicinity of Dos Cabezos, Ariz., in June, 1894, which may be accounted for in this way. In 1921 Vorhies found all mounds within 4 or 5 miles of Albuquerque, N. Mex., deserted by *spectabilis*, resulting probably from overgrazing by sheep and goats during a succession of dry years. In the arid Southwest natural selection probably favors the animals with the largest food stores, and it is not surprising that the storing habit has been developed to a remarkable degree.

Some stored material is likely to be found at any time of year in any mound examined, the largest quantity usually in fall and winter, the smallest in July or August (Table 1, dens 1, 2, 14, and 24). Amounts found by different observers vary from a few ounces to several quarts or pecks, and stored materials taken from 22 mounds on the Range Reserve vary in weight from 5 to 4,127 grams (more than 9 pounds). This is exceeded by one lot from New Mexico, which totaled 5,750 grams (12.67 pounds). It is fairly evident that in seasons of scanty forage for stock the appropriation of such quantities of grass seeds and crowns and other grazing materials by numerous kangaroo rats may appreciably reduce the carrying capacity of the range. Studies of cheek-pouch contents and food stores taken from dens show that the natural food of *spectabilis* consists principally of various seeds and fruits, particularly the seeds of certain grasses. The study of burrow contents has been especially illuminating and valuable.

All of the stored material from 22 dens on the Range Reserve and from 2 near Albuquerque, N. Mex., has been saved and analyzed as to species as carefully as the conditions of storage would permit. Within the mound the food stored is usually more or less segregated by plant species, though the stores of material of any one kind may be found in several places through the mound, and often the material is mixed. In the latter case the quantities of the various species can only be estimated, but in the former the species may be kept separate by the use of several bags for collecting the seeds, and a fairly accurate laboratory weighing can be made later. Very frequently, the explanation of this separation of species lies in the different seasons of ripening, but sometimes where two species are ripe at the same time near the mound, one is worked upon for a time to the exclusion of the other. The one kind is often packed in tightly against the other, but with a very abrupt change in the character of the material.

A number of the more interesting and representative results of the weighing and analyses of burrow contents are presented herewith in tabular form. The data for each den, or lot, shows in grams the quantity of stored material removed and the best estimate it was possible to make of the percentages or weights of the various species. When the weight was less than 5 grams, the mere trace of the species frequently is indicated in the following tables by the abbreviation "Tr."

TABLE 1.—*Analyses of plants stored by* Dipodomys spectabilis spectabilis *Merriam, obtained from examination of representative dens (all except Den 24 from U. S. Range Reserve, near the Santa Rita Mountains, Ariz.).*

DEN 1.

February 7, 1918. Burrow typical, located on bank of wash in partially denuded grass-land. *Bouteloua rothrockii* and weed type; soil sandy; burrow photographed in section (Pl. VII, Fig. 1).

Species stored.	Grams.
Bouteloua rothrockii	2,205
Bouteloua aristidoides (B. eriopoda and B. rothrockii, Tr.)	1,445
Plantago ignota	442
Eriogonum polycladon	35
Total	4,127

Four species of plants represented in burrow contents (Pl. VII, Fig. 2). Maximum quantity for single burrow in series of 22 from Range Reserve.

DEN 2.

March 9, 1918. Surroundings overgrazed and partially restored by complete protection. Red soil, with much coarse rough gravel and stone.

Species stored.	Grams.
Bouteloua rothrockii (nearly pure)	1,460
Bouteloua rothrockii (mixed with Aristida spp.)	945
Boerhaavia wrightii	660
Bouteloua rothrockii Bouteloua aristidoides Aristida divaricata Aristida bromoides	525
Kallstroemia laetevirens	Tr.
Heterotheca subaxillaris	Tr.
Plantago ignota	15
Fleshy fungi	10
Total	3,615

Eight species of plants represented by seeds. One species of fleshy fungus in addition.

FIG. 1.—DEN EXCAVATED ON RANGE RESERVE.

Vertical section through Den No. 1, of Table 1 (p. 20), showing the complex system of burrows, some of them plugged with closely packed storage (outlined in white), the depth of the den ,and the widened chambers centrally located.

FIG. 2.—CONTENT OF EXCAVATED DEN.

Storage content of Den No. 1 (Fig. 1, above), showing the separate species of plants listed in Table 1. The rod is 1 meter long. The large pile on the left is composed of seed-laden heads of crowfoot grama (*Bouteloua rothrockii*), the large pile on the right consists of heads of six-weeks grama (*Bouteloua aristidoides*), the pile of heads in the center is desert plantain (*Plantago ignota*), and the smallest heap is composed of buckwheat-bush seeds (*Eriogonum polycladon*).

Den 4.

September 20, 1918. In *Calliandra* type. Stony or gravelly soil, red, nearly denuded of grass.

Species stored.	Per cent.	Grams.
Prosopis velutina		190
Mollugo verticillata (pure)		90
Anisolotus trispermus (mixed, but mostly of this genus)		50
Solanum elaeagnifolium (12 fruits)		2
Mollugo verticillata (inseparable)	50	400
Bouteloua rothrockii	1	
Bouteloua aristidoides	10	
Lepidium lasiocarpum	Tr.	
Polygala puberula	Tr.	
Ayenia microphylla	2	
Portulaca suffrutescens	1	
Aplopappus gracilis	Tr.	
Alternanthera repens	1	
Tridens pulchella	1	
Plantago ignota	33	
Panicum hallii	Tr.	
Fleshy fungi (puffballs)		2
Total		734

Fifteen species represented in addition to the fleshy fungi. No perceptible grass growth from the summer rains here, therefore dependent on a wide variety of scattering plants.

Den 6.

October 17, 1918. Mixed type, partially denuded, no growth from summer rains. Sandy soil.

Species stored.	Grams.
Bouteloua rothrockii (crowns) (heads 1 to 2 per cent)	1, 435
Bouteloua rothrockii (heads and crowns, about 50 per cent of each)	325
Bouteloua rothrockii (with small percentage of crowns)	315
Boerhaavia wrightii (with a few grass crowns)	150
Prosopis velutina	90
Solanum elaeagnifolium (3 fruits)	Tr.
Total	2, 315

Four species represented. Count of 100 grams of stored *Bouteloua* crowns gives 1,700, or 17 crowns per gram. At this rate there were at least 27,000 crowns stored in this burrow. If a density of 250 plants to the square yard be assumed (a high estimate) these crowns represent the total *B. rothrockii* on 104 square yards of range surface. Further examination of the vicinity of this den showed that the surrounding area was not completely cleared, but was devoid of *B. rothrockii*, while still having *B. eriopoda* with crowns undisturbed.

Den 11.

April 9, 1919. In partially denuded land where good spring growth of *Eschscholtzia* was in bloom at time of excavation. Stomach of *spectabilis* killed

in this burrow contained a mass of fresh but finely comminuted green material, probably poppy leaves, strongly colored with yellow from blossoms. No summer growth here in 1918.

Species stored.	Grams.
Bouteloua rothrockii (crowns) (miscellaneous chaff, etc.)	107
Eschscholtzia mexicana (buds and flowers)	10
Anisolotus trispermus (leaves and pods)	
Gaertneria tenuifolia (leaves)	
Lupinus sparsiflorus (flowers)	
Solanum elaeagnifolium (2 fruits)	Tr.
Total	117

Six species represented, some only by leaves or flowers and not by seeds. *Such storage is never in large quantity.* The fresh storage material was weighed after becoming air dry. This illustrates a late spring condition, storage running low.

Den 14.

August 8, 1919. Excellent summer growth all over range. This burrow in mixed growth, grasses and weeds.

Species stored.	Grams.
Miscellaneous portions of *green plants* of mixed species, *no seeds*	5

Representing minimum for any one of the 22 burrows studied. Active storage does not begin until September.

Den 16.

October 17, 1919. In good grass, but mound overrun by a large *Apodanthera* vine.

Species stored.	Per cent.	Grams.
Aristida divaricata	90 to 95	58
Chamaecrista leptadenia	10 to 5	
Bouteloua rothrockii	Tr.	
Prosopis velutina		200
Apodanthera undulata		55
Total		313

Five species represented. Two species, *Apodanthera* and *Chamaecrista leptadenia*, new to storage records. Several whole fruits of *Apodanthera*, about 2 inches in diameter, stored in addition to seeds alone; seeds of this form not previously noted in burrows, but very abundant in this one, indicating importance of the factor of accessibility in storage.

Den 19.

October 31, November 1, 1919. In good grass. Entire burrow system mapped (Fig. 2, p. 29).

Species stored.	Per cent.	Grams.
Aristida spp. (probably mostly *divaricata*)	98	1, 813
Eriogonum sp	Tr.	
Bouteloua rothrockii	1	
Bouteloua aristidoides	1	
Panicum sp	Tr.	
Prosopis velutina		1, 213
Total		3, 026

Five species represented, in addition to those of *Aristida*. Largest storage of *Prosopis* found. Mound was near a good-sized mesquite tree. No storage in subsidiary burrows.

DEN 21.

January 31, 1920. Male trapped here night of January 29, and suckling female trapped at same place and same opening of mound, night of January 30. Burrow excavated to secure young, which were found in special nest chamber.

Species stored.	Grams.
Aristida spp. (intimate mixture of undetermined species)	1,115
Eschscholtzia mexicana (from spring of 1919)	48
Opuntia (prickly pear, seeds only, no fruits)	10
Total	1,173

Three species represented. Prickly pear hitherto found as fruits only.

DEN 22.

January 1, 1921. Rather good grass growth here in summer of 1920. Burrow typical, sandy soil. Two skulls of former residents unearthed.

Species stored.	Grams.
Aplopappus gracilis (some B. rothrockii)	1,030
Astragalus nuttallianus	630
Bouteloua rothrockii (some A. gracilis)	530
Sida diffusa	30
Solanum elaeagnifolium (282 fruits)	53
Loeflingia pusilla	Tr.
Bouteloua aristidoides	Tr.
Plantago ignota	Tr.
Lupinus sparsiflorus	Tr.
Old storage (mostly Bouteloua aristidoides with traces of B. rothrockii and Aristida divaricata)	60
Total	2,333

Eleven species represented. First instance of quantity storage of *Aplopappus gracilis*. First occurrence of *Loeflingia pusilla* and *Astragalus nuttallianus*.

DEN 24.

November 8, 1921. On mesa northeast of Albuquerque, N. Mex., near base of Sandia Mountains. Fair grass growth here during preceding summer.

Species stored.	Grams.
Sporobolus cryptandrus strictus	5, 455
Salsola pestifer	295
Total	5, 750

Two species represented. The heads of *Sporobolus cryptandrus strictus* are retained to a great extent within the leaf sheaths. This necessitates the cutting of the stems into suitable lengths for carrying, and the stored material appears to be merely cut sections of the stems. Close examination, however, discloses the heads within, and shows that as in other instances seed storage is the end sought. These pieces are packed beautifully parallel like so many matches.

and vary from a minimum length of 20 to a maximum of 37 millimeters, averaging about 30. Count of 2 grams of the above *Sporobolus* material shows that there are 125 separate cut sections per gram, or a total of approximately 680,000 pieces in this one lot of storage, indicating a remarkable activity on the part of the individual rat (Pl. VIII, Fig. 1).

The number of lots of storage (24) studied in detail, extending as it does over a period of three years with seasons of varying growth conditions, is not sufficient to permit the construction of a curve showing increase and decrease in quantity of stored material with growing seasons and intervals between; but the results indicate a very decided increase during the autumn storing season, and continuing large well into the winter, since some outside material can still be obtained until midwinter. From about February to April a decrease may be noted, followed, if the spring growth of annuals be good, by a slight increase; and we can very nearly predict the general character of the increases and decreases by the precipitation and consequent growth conditions.

TABLE 2.—*Quantity of storage per den correlated with time of year and growth conditions of preceding season (chiefly from United States Range Reserve near the Santa Rita Mountains, Ariz.).*

Den No.—	Date.	Quantity.	Preceding season.	Den No.—	Date.	Quantity.	Preceding season.
	1918.	*Grams.*			1919.	*Grams.*	
1	Feb. 7	4,127	Good.	14	Aug. 8	5	Good.
2	Mar. 9	3,615	Do.	15	Sept. 4	151	Do.
3	July 25	401	Poor.	16	Oct. 17	313	Do.
4	Sept. 20	734	Do.	17	Oct. 18	583	Do.
5	Sept. 21	2,520	Do.	18	Oct. 25	3,410	Do.
6	Oct. 17	2,315	Do.	19	Nov. 1	3,026	Do.
7	Dec. 20	1,247	Do.	20	Dec. 13	2,816	Do.
	1919.				1920.		
8	Feb. 7	1,600	Do.	21	Jan. 31	1,173	Do.
9	Mar. 13	370	Do.				
10	Apr. 7	180	Do.[1]		1921.		
11	Apr. 9	117	Good.[1]	22	Jan. 1	2,333	Fair.
12	May 7	2[illegible]8	Do.[1]	23[2]	Nov. 7	1,685	Good.
13	May 11	1,590	Do.	24[2]	Nov. 8	5,750	Do.

[1] Changing from poor summer season of 1918 to excellent spring growth of 1919.

[2] From near the Sandia Mountains, N. Mex.; others from United States Range Reserve, near the Santa Rita Mountains, Ariz.

In presenting Table 2, showing quantity of storage per burrow correlated with the time of year and the character of the preceding growing season, the fact may be emphasized that the growing seasons in southern Arizona are two in number—early spring and midsummer. The spring season is the less important, the plants consisting chiefly of a variety of small annuals, while the important range grasses make their chief growth and head out almost exclusively in the July-August rainy season. It may be noted also that the actual

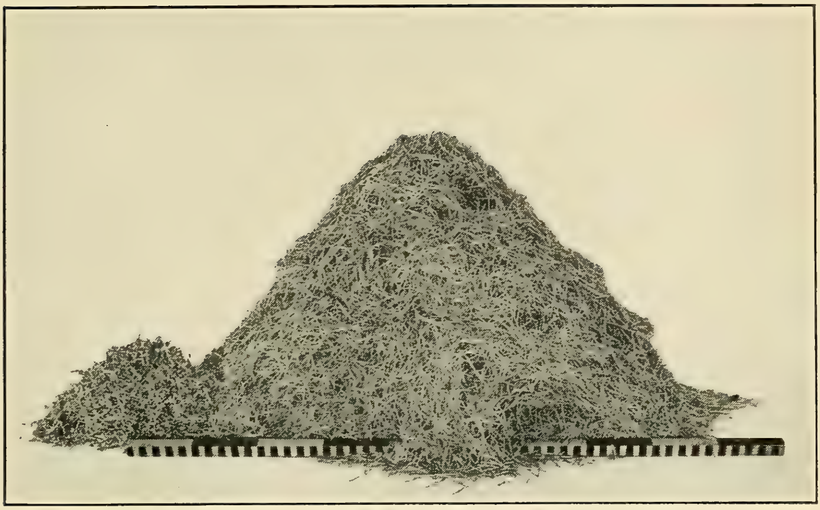

FIG. 1.—CONTENT OF DEN EXCAVATED IN NEW MEXICO.

Storage content of Den No. 24, of Table 1, from Sandia Mountains, N. Mex. This is the largest lot of storage taken in the course of the investigations. The larger pile consists wholly of a valuable grass ,*Sporobolus cryptandrus strictus:* the smaller of Russian thistle (*Salsola pestifer.*)

FIG. 2.—GROWTH FOLLOWING ELIMINATION OF KANGAROO RATS.

The same mound as shown in Plate III, Figure 1, after three years of protection, the rodents having been killed out. Nearly as good grass recovery following poisoning operations occurred in the single excellent season of 1921.

increases in storage appear somewhat after the growth period proper, since storing does not get well under way until the seed crop is mature. The banner-tailed kangaroo rat shows a marked adaptability to different foods available in the neighborhood of its burrows. It must, perforce, adapt itself and its storage program to the food that it can get, and this varies enormously with the climatic conditions of successive seasons. The large numbers present in suitable localities clearly indicate that the animal is successful in meeting the changing and sometimes extremely adverse conditions of its environment.

At times, more especially in the seasons of active growth, some of the green and succulent portions of plants are eaten. This was very noticeable in the spring of 1919, when a most luxuriant growth of Mexican poppy (*Eschscholtzia mexicana*) occurred. Stomachs at this time were filled with the yellow and green mixture undoubtedly produced by the grinding up of the buds and flowers of this plant. Small caches of about a tablespoonful of these buds were also found in the burrows at this time. Occasionally in spring one may find a few green leaves of various plants, *Gaertneria* very commonly, tucked away in small pockets along the underground tunnels, indicating that such materials are used to some extent. As has been shown in detail, however (Table 1), the chief storage, and undoubtedly the chief food, consists of air-dry seeds.

The character of the storage, the absence of rain for months at a time in some years, and the consequent failure of green succulents show that without doubt *spectabilis* possesses remarkable power, as to its water requirements, of existing largely if not wholly upon the water derived from air-dry starchy foods, i. e., metabolic water serves it in lieu of drink (Nelson, 1918, 400), this being formed in considerable quantities by oxidation of carbohydrates and fats (Babcock, 1912, 159, 170). During the long dry periods characteristic of southern Arizona, no evidence that the animal seeks a supply of succulent food, as cactus, is found; and if it may go for two, three, or six months without water or succulent food, it is reasonable to suppose that it may do so indefinitely. In the laboratory *spectabilis* ordinarily does not drink, but rather shows a dislike for getting its nose wet. During the periods of drought the attacks upon the cactuses by other rodents of the same region, as *Lepus*, *Sylvilagus*, *Neotoma*, and *Ammospermophilus*, become increasingly evident. The list of plant species thus far found represented in the storage materials of *spectabilis* on the Range Reserve is shown in Table 3.

TABLE 3.—*List of all plant species found in 22 dens of* Dipodomys spectabilis *on the United States Range Reserve, near the Santa Rita Mountains, Ariz., with approximate total weights.*

GRASSES.

	Grams.
Aristida bromoides (six-weeks needlegrass)	536
Aristida divaricata (Humboldt needlegrass)	9,412
Aristida scabra (rough needlegrass)	344
Bouteloua aristidoides (six-weeks grama)	3,093
Bouteloua radicosa (grama)	1,269
Bouteloua eriopoda (black grama)	Tr.
Bouteloua rothrockii (seeds, 8,495; crowns, 3.517 grams) (crowfoot grama)	12,012
Festuca octoflora (fescue grass)	70
Panicum arizonicum (Arizona panic-grass)	11
Panicum hallii (Hall panic-grass)	Tr.
Pappaphorum wrightii	Tr.
Tridens pulchella	Tr.
Valota saccharata	Tr.

OTHER PLANTS.

Alternanthera repens	Tr.
Anisolotus trispermus (bird's-foot trefoil)	186
Aplopappus gracilis	1,030
Apodanthera undulata (melon loco)	55
Astragalus nuttallianus (milk vetch)	630
Ayenia microphylla	Tr.
Boerhaavia wrightii	885
Chamaecrista leptadenia (partridge pea)	5
Echinocactus wislizeni (visnaga)	5
Eriogonum polycladon	35
Eschscholtzia mexicana (Mexican poppy)	250
Gaertneria tenuifolia (franseria)	Tr.
Collomia gracilis (false gilia)	Tr.
Heterotheca subaxillaris	Tr.
Kallstroemia laetevirens	Tr.
Lupinus sparsiflorus (lupine)	Tr.
Martynia altheaefolia (small devil's-horns)	12
Mollugo verticillata (carpetweed)	324
Oenothera primiverus (evening primrose)	15
Opuntia discata (prickly pear)	15
Loeflingia pusilla	Tr.
Lepidium lasiocarpum (peppergrass)	Tr.
Plantago ignota (plantain)	818
Polygala puberula (milkwort)	Tr.
Portulaca suffrutescens (purslane)	Tr.
Prosopis velutina (mesquite)	1,570
Sida diffusa (spreading sida)	30
Solanum elaeagnifolium (742 fruits) (trompillo, prickly solanum)	156
Puffballs and fleshy fungi (undetermined)	12

Total species, exclusive of fungi, 41.

It will be seen from Table 3 that while a large number of species of plants are represented in the totals from so many dens, a majority of them are of very minor importance, and that the seeds of grasses are the principal storage and probably therefore the principal food material. Six of the most important species of grasses (disregarding species furnishing less than 5 grams) comprise 85.6 per cent of the total weight of storage from 22 dens. Crowfoot grama (*Bouteloua rothrockii*) stands first in quantity in the total, forming 39.4 per cent of all stored material, 46 per cent of the six important grasses, and 45 per cent of all grasses. The largest amount of storage of any one species of grass in any one den on the Range Reserve also is of this species, 2,205 grams[3] (Table 1, den 1, p. 20, and Pl. VII, Fig. 2). This is exceeded by a dropseed grass, *Sporobolus cryptandrus strictus*, which amounted to 5,455 grams in a lot from Albuquerque, N. Mex. (Table 1, den 24, and Pl. VIII, Fig. 1).

Of the species other than grasses found stored in these dens, mesquite beans (*Prosopis velutina*) are most important both by weight and number of dens containing them. The total for the 22 Range Reserve dens is 1,570 grams, or 35.9 per cent of the seeds other than grasses, but only 5.1 per cent of the total storage. In bulk mesquite beans do not loom up large, as they are probably the heaviest material stored. Sections of pods which must have been dragged into the burrows are found, some of them certainly being much too long for carriage in the pouches. The species of plant other than grass found in the largest quantity in any one den, however, was *Aplopappus gracilis*, not recorded in quantity from any den until the excavation of the twenty-second, and then found in a very large bulk of soft, fluffy material, with most of the seeds separated from the heads, and weighing 1,030 grams (Table 1, den 22).

Any of the food materials above listed are likely to be found in the cheek pouches, while in addition such extraneous matter as stones and feces have also been found. All species of plants stored are accessible in the immediate vicinity of the mound, and when any particular plant is found seeding in abundance in the vicinity of the den it is likely to be represented in the storage. Usually the animals can be readily trapped with almost any kind of grain bait, as oats, rolled oats, rolled barley, and wheat; and nut meats also are attractive, though we have no record of the storing of any true nut in the dens, such not being available in the range of the animal on the Range Reserve.

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[3] This amount of dry grama grass seed (heads) amounts to approximately a bushel.

The following plants not represented in the list stored by the kangaroo rat on the Range Reserve have been found in the cheek pouches or mounds of *spectabilis* in other localities:

Amaranthus palmeri, *Sesuvium portulacastrum*, and *Atriplex wrightii* (alluvial soil of Santa Cruz Valley, Continental, Ariz., Bailey).

Cut leaves and stems of a small sagebrush (Franklin Mountains, Tex., Gaut).

Gutierrezia heads (San Juan Valley, N. Mex., Birdseye).

Verbesina enceliodes, *Portulaca oleracea*, *Bouteloua gracilis*, and *Munroa squarrosa* (Rio Alamosa, N. Mex., Goldman).

Tops of buds of *Artemisia filifolia* (Mesa Jumanes, N. Mex., Gaut).

Tumbleweed (*Amaranthus graecizans*), Russian thistle (*Salsola pestifer*), *Munroa squarrosa*, and *Sporobolus cryptandrus strictus* (Sandia Mountains, Albuquerque, N. Mex., Vorhies).

BURROW SYSTEMS, OR DENS.

The burrow system, or den, in which *spectabilis* stores its caches of food materials, has its nest, and remains throughout the hours of daylight is a complicated labyrinth of tunnels. Ejection of refuse and soil from this retreat builds up the mound frequently referred to. These mounds are, as Bailey says, characteristic of the species, and are as unmistakable as muskrat houses or beaver dams, and as carefully planned and built for as definite a purpose—home and shelter. They are, furthermore, the most notable of all kangaroo rat dwelling places (Nelson, 1918, 400). They range in height from 6 inches to approximately 4 feet and from 5 to 15 feet in diameter.

The mound is built up not only through the cleaning out of chaff and other food refuse, but through extension and modification of the tunnels; old tunnels, entrances, and caches of musty food material are from time to time closed up and others excavated, repair and rebuilding being especially necessary after the collapse of portions of the den as a result of heavy rains or trampling by cattle. Ejected material is most commonly simply thrown out fan-wise from the openings, without much apparent effort to add to the height of the mound.

There are usually from 6 to 12 entrance holes in each mound opening into the subterranean burrow system, each hole from 4 to 5½ inches in diameter. These holes are nearly all situated a little above the surface of the surrounding soil, and as Price has suggested (in Allen, 1895, 213), this is doubtless a wise provision against flooding, as torrential rains sometimes occur in the kangaroo rat country.

Both Bailey and Nelson state that as a rule several of the holes are closed with sand or miscellaneous earth and old storage material during the daytime, but our observations on the Range Reserve are that such closing is only occasional. Many occupied dens have not

a single opening closed. Further, night observations disclose that the inhabitant of the mound will appear from some one of the two or three most-used openings when night falls, and not necessarily from one which has been closed by day. Recently an opening closed one day was observed in use during the night, but was left open all the next day.

In attempting to determine whether there exist similarities of plan or system in the dens, it was considered advisable to map them with

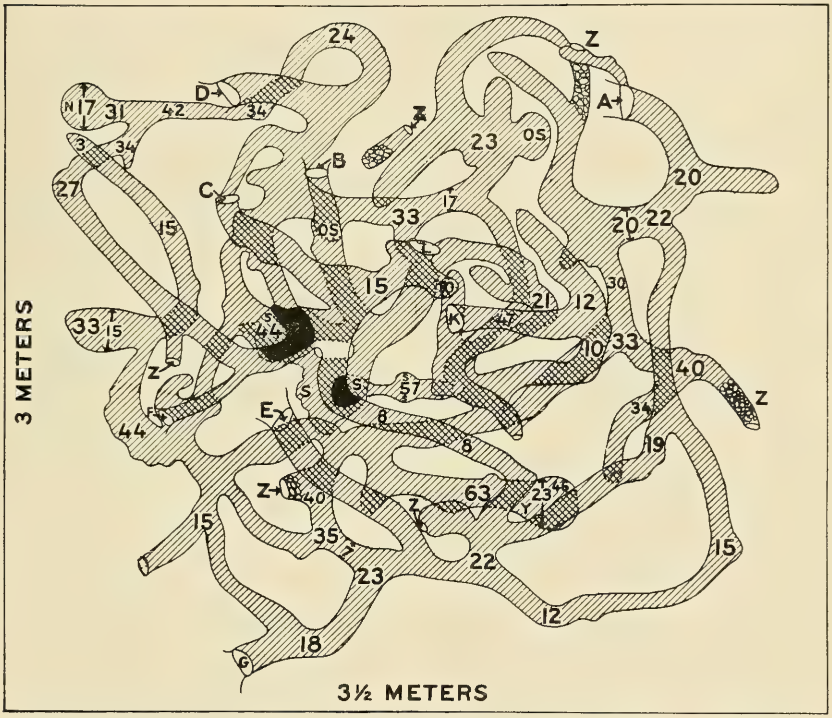

Fig. 2.—Diagram of a typical den of *Dipodomys spectabilis spectabilis*. Double shading indicates where one portion of tunnel lies above another and solid black a three-story arrangement; *A, B, C,* etc., active openings to surface; figures without arrows, depths in centimeters to tunnel roofs; figures with arrows, tunnel widths in centimeters; *N*, nest chamber; *S*, storage; *OS*, old storage; *Y*, probably an old nest chamber; *Z*, old, unused, or partially plugged openings.

some degree of accuracy. This we were enabled to do by laying off a square about a given mound, 2½ or 3 meters each way, and subdividing it into a series of small squares of half a meter on each side by drawing cross-lines on the surface of the ground over the top of the mound. One person then did the digging and exploring of the tunnels, as to direction and depth, while the other noted the results on coordinate paper (Figs. 2 and 3); the proper excavation and mapping of one of these workings occupied from four to eight hours for the two.

While there is greater complexity in the larger, and probably older, mounds than in the smaller, all are extremely complicated and can only be described as labyrinthine in character. The tunnels wind about through the mound, rising and falling in vertical depth, intercommunicating frequently, but with occasional cul-de-sacs, and in places expanding into chambers, of which there may be three or four large ones. The stored materials are found in some, but not necessarily all, of these chambers, and may also occupy considerable lengths of ordinary tunnel, especially when the quantity present is large. Small evaginations of the tunnels frequently contain lesser caches, and it is in such pockets that bits of fresh material are placed during a growing season, or that grain supplied the previous night for bait is usually found.

The main masses of storage are most often found centrally located at depths of from 15 to 57 centimeters, although at times one may find a cache near the periphery of the system and as near the surface as 2 or 3 centimeters. In the latter case the materials are subject to wetting from rains, and consequent spoilage.

The major portion of the whole tunnel system is within about 50 centimeters of the surface of the mound, but usually some one branch tunnel goes to somewhat greater depth, and this is likely to be the one containing the nest; this is also likely to extend toward or beyond the periphery of the main system, and always ends blindly. Such a one, from which two young were taken on January 31, 1920, was at a depth of about 65 centimeters, and about $1\frac{1}{2}$ meters beyond the periphery of the mound itself.

The individual tunnels average about 8 centimeters in height, and about 11 centimeters in width, though the variation, especially in width, is considerable. The expansions mentioned as being the chief places of storage are from 15 to 25 centimeters in diameter, and may or may not involve a considerable increase in height. They are frequently located at junction points of two or more branches of the tunnel system.

The nest cavity is a chamber of approximately spherical shape and from 17 to 23 centimeters in diameter. Chambers of this character were observed and noted as "old storage" in a number of cases. They were sometimes cut off from the rest of the habitation, and at first were supposed to contain abandoned musty storage. As experience in excavating and interpreting results has been gained we have concluded that these chambers in fact represent abandoned nests.

Bailey gives the dimensions of nest chambers observed in New Mexico as about 6 by 8 inches to 8 by 10 inches. The nest is composed of finer, softer, and more chaffy material than the regular

storage. The chaff refuse from the food probably contributes largely to it, though some leaves of grasses not stored for food may also be found, and a nest, especially the one in use, may be distinguished, if excavating is carefully done, by the distinct cavity about the size

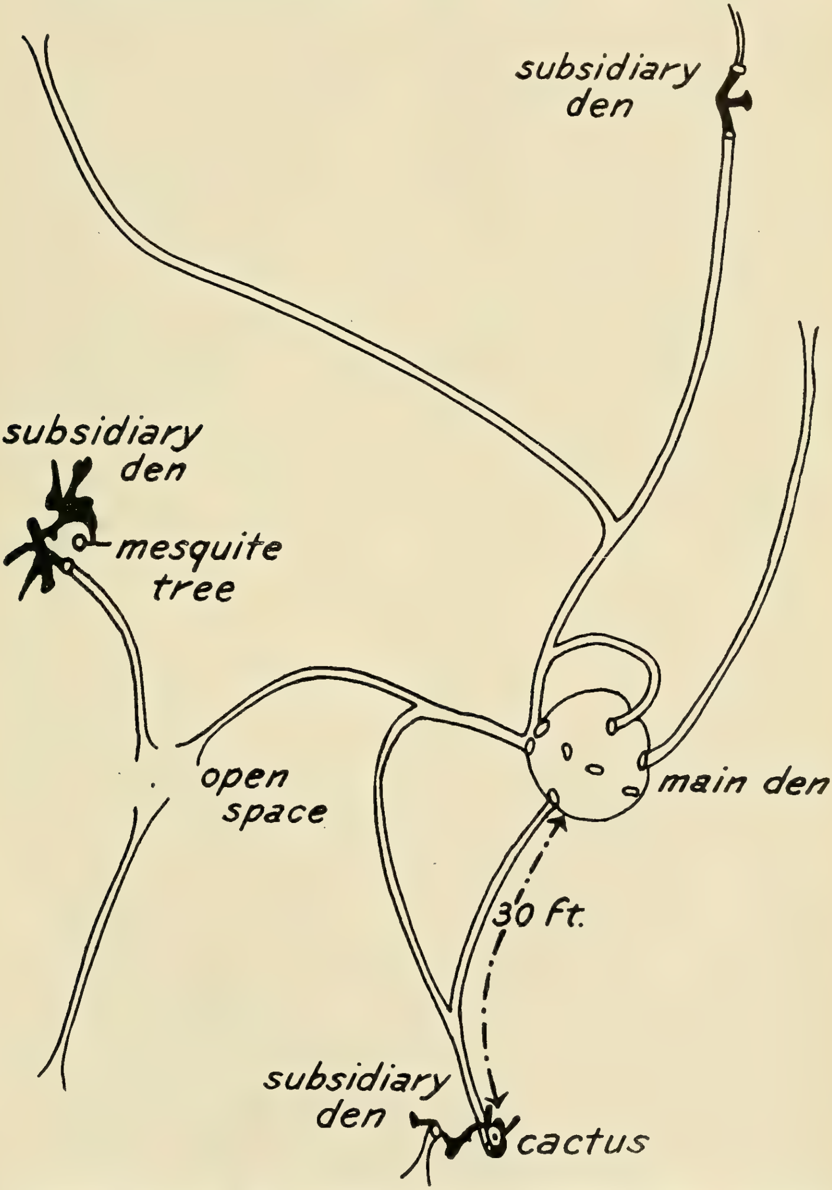

FIG. 3.—Diagram of the system of surface runways and subsidiary dens of *Dipodomys spectabilis spectabilis.* The underground tunnels of the main den were too complicated to illustrate on this scale, being very similar to those of Figure 2. The underground tunnels of the subsidiaries are shown in solid black. Some runways fade out in the grass in a manner that can not be indicated in a line drawing.

of a fist in its interior (Pl. IX, Fig. 1). One may sometimes find this cavity distinctly warm from the recent presence of the inhabitant.

The walls or partitions between the chambers and tunnels are in places surprisingly thin, and it is no wonder that one is almost certain to break through in stepping on a mound, since the whole is a honeycomblike structure of from two to four stories in vertical plan, as shown by the transect of a mound in Plate VII, Figure 1. As Bailey writes, these partition walls are a mixture of earth and old food and nest material discarded years ago, resembling the adobe walls of the Mexican houses built of chopped earth and straw. This is the result of the continual ejection of refuse and earth as before mentioned, combined with the caving action of rains and disturbances from larger animals.

Apparently there are no special pockets for deposit of feces in *Dipodomys* burrows: such matter may be found throughout the den, and is more or less mixed with the food refuse which carpets practically the entire tunnel system. The nest and food stores are, however, clean and neat, the droppings being dry and, though present on the floor of a storage chamber, not actually mingled with the food. Evidently the animal does not clean up the floor litter before storing food material.

The entire system for any one den seems to consist not only of the burrows within the mound itself, as described, but of those small outlying ones which we have referred to as subsidiary burrows. These are two to four in number, and are connected with the main mound by the runways already mentioned. They often seem to be way stations on the runways connecting main mounds, and there is seldom any mound of earth whatever in connection with them. One entire den system, the home mound and three subsidiaries, was mapped after being excavated (Fig. 3), all having been carefully gassed with carbon bisulphide. The subsidiaries were simple and contained no storage. Two of them were shallow, while in the third a depth of 48 centimeters was reached. They appear to be merely places of refuge, though the well-worn trails connecting them with the main mound indicate regular use. These runways are conspicuous on the Range Reserve, and are apparently characteristic of mounds throughout the range of the animal. Dwellers in different mounds must have rather extensive social contacts, notwithstanding the enmity of individuals toward each other in captivity. The main mound, in this instance very complicated, was in one place three stories high, and we have found as many as four utilized stories; but as a rule there are two or three only.

Since collapses are rather frequent during rainy seasons, aside from the trampling previously referred to, the kangaroo rats, where

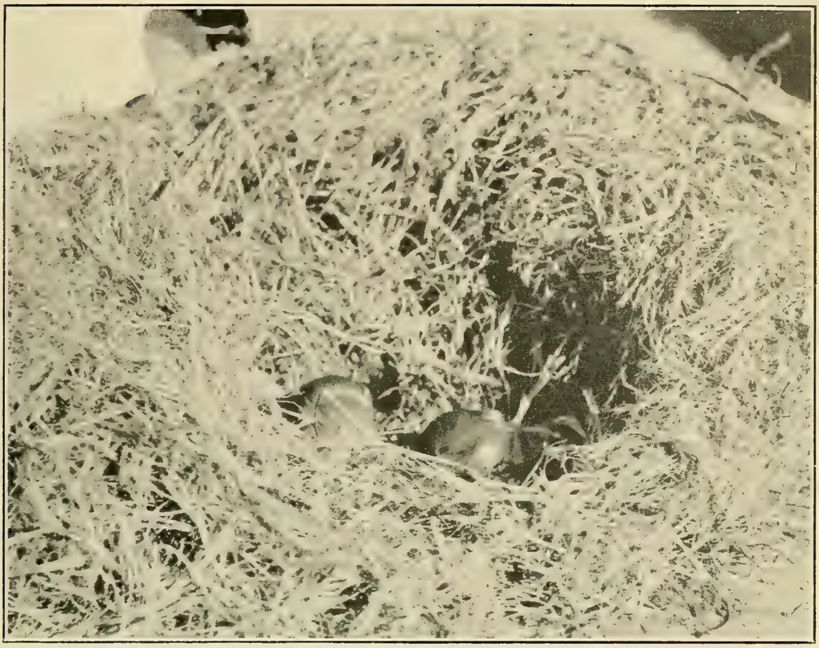

FIG. 1.—KANGAROO RAT NEST AND YOUNG.

Nest and the two young, the ordinary number in the litter, of *Dipodomys s. spectabilis,* taken from den on January 31, 1920.

FIG. 2.—YOUNG OF THE KANGAROO RAT.

The same young as shown in Figure 1, above. They were probably about two weeks old, the pelage being short but with the white markings of the adult; the tails are relatively short and with scarcely any hair.

abundant, as on the Range Reserve, may well be a factor in increasing soil porosity and fertility; for in the course of time they probably have succeeded in plowing and cultivating the whole surface layer of the soil. They may thus be a factor in ecologic succession, tending to improve the character of the soil and adapt it to another stage.

Doubtless their own workings afford the only shelter the animals know. In the course of our digging in one mound, the occupant, an adult male, did not forsake the den until the excavation was three-fourths completed; and even then it did not leave by a burrow leading away from our operations, but came toward us, escaped the active efforts of four individuals bent on its capture, and ran speedily along a used runway toward another burrow several meters distant. A sack had been stuffed in the mouth of this, however, and, baffled, the rat then returned to the original burrow and was captured. Observations on other rats thus driven from the home mound indicate that they are very familiar with the runways of the vicinity of the mound and the various subsidiary burrows, and it is a question whether they need to see clearly to follow these runs. Apparently they never attempt to escape by forsaking their well-traveled runways. Tests of the maze-running ability of these animals by animal-behavior experts would be of extraordinary interest, in view of the character of the homes which they always inhabit and the network of runs on the outside.

COMMENSALS AND ENEMIES.

COMMENSALS.

It is doubtful whether any animals live in a truly commensal relationship with *spectabilis*, but of not unfriendly associates there are a great number. It is the experience of Bailey, corroborated by observations of Vorhies on living animals, that these kangaroo rats are active in defending their caches of food, and will even fight individuals of the same species savagely and to the death. One moonlight night a strange individual was liberated on a mound. It deliberately entered one of the openings, but after about two minutes' time made an exceedingly rapid exit, running rapidly out of sight as if pursued, though the owner of the home did not appear outside of the burrow. There can be little doubt that the stranger was precipitately ejected by the owner. We suspect, though this is a point difficult to prove satisfactorily, that *merriami* does not always store food supplies for itself, but visits the burrows of *spectabilis* regularly to pilfer the seed stored therein. The observed facts thus far recorded which suggest this are that in no *merriami* burrow examined has a store of food been found, and also that in

trapping for *spectabilis* on its own characteristic mounds one catches a large percentage of *merriami*.

On two separate occasions Vorhies has observed the smaller species running over the mounds of the larger, actually carrying away the grain which had been placed to entice the larger when it might appear. (In these cases the larger species did not put in an appearance until near morning.) Furthermore, the dens of *merriami* are often connected by distinct runways with those of *spectabilis*, indicating much traveling or visiting. That this is probably not friendly visiting is suggested by the certainty with which an individual of the larger species will strike and kill one of the smaller when they are placed together in the same inclosure. The word "thief" expresses this suspected relationship better than would the term "parasite."

It is not to be expected that such obvious shelter retreats as the mounds of *spectabilis* should fail to attract the attention of other animals. We have found a small gecko (*Coleonyx variegatus*), scorpions of two or three undetermined species, and certain insects (of the Order Orthoptera) to be very common inhabitants of the dens. With the exception of the parasitic insects the most common are wingless locustids (*Ceuthophilus* spp.) and the peculiar wingless females of a species of cockroach (*Arenivaga erratica*). These two are seldom absent when a burrow is excavated, the female cockroaches being abundant, although the winged males have never been taken in the burrows.

Cary's observations at Monahans, Tex., and those of others at numerous localities, combined with our own, show that at various times the dens furnish protection and shelter for various species of cottontail rabbits (*Sylvilagus*), ground squirrels (*Citellus* and *Ammospermophilus*), wood rats (*Neotoma*), grasshopper mice (*Onychomys*), rattlesnakes (*Crotalus*), and most of the common lizards. Of these the ground squirrels *Citellus tereticaudus* and *Ammospermophilus harrisii* are most often noted on the Range Reserve using the dens as a retreat, the *Ammospermophilus* seldom being observed to enter any other kind of burrow. It should be added that the total observations include dens which have been deserted by their rightful owners.

NATURAL CHECKS.

The enemies of the kangaroo rat are not determined in detail, or as to relative importance, but the badger (*Taxidea taxus berlandieri*) and the kit fox, or swift (*Vulpes macrotis neomexicana*), may well be foremost. Dens which have been deeply excavated by badgers are frequently seen, and sometimes two or three badger tunnels penetrate one burrow system. Dens thus despoiled are

probably soon reoccupied even if the original owner is captured, and in the course of a few months the reworking of the abode obliterates the signs of destruction.

Droppings of the kit fox show an abundance of bones of small mammals of kangaroo rat size, among them those of *spectabilis.*

Bobcats (*Lynx baileyi*) and coyotes (*Canis mearnsi*) probably are a prejudicial factor. Skunks may sometimes be able to surprise the kangaroo rats, but probably not often. The western horned owl (*Bubo virginianus pallescens*), the barn owl (*Tyto alba pratincola*), and perhaps others may well be among the most feared enemies, but no special investigation of owl pellets on the reserve has been possible. In 592 barn-owl pellets from California were found remains of 230 kangaroo rats, only one other rodent being represented by a larger number (McAtee, 1921, 258).

Much more information on enemies is needed. The relatively low rate of reproduction (see p. 18) indicates comparative freedom from inimical factors.

PARASITES.

Dipodomys s. spectabilis is regularly infested with a species of flea, *Ctenophthalmus* sp. Seldom or never is a specimen taken in reasonably fresh condition without some of these parasites present on its body, though of course they desert the body of the host after it becomes cold, and hence dead specimens left too long may be free from them. The den conditions are ideal for the breeding of this parasite, because of the great quantities of fine, dusty, organic refuse littering the tunnels and furnishing food and refuge for the larvæ. As demonstrated to us by F. C. Bishopp, of the Bureau of Entomology, a handful of this refuse taken from the floor of a burrow within arm's length of the entrance is almost certain to contain these larvæ.

Less regularly present, perhaps because of its different life history, is a small tick, *Trombicula* sp. At times this parasite is very common, being present on nearly every individual rat, and at other times specimens are difficult to find; it appears to be more commonly present in summer and fall than at other seasons, and is found attached chiefly to the ears.

No internal parasites have been detected. The nocturnal and fossorial habits of the animal seem to give complete protection against a form of parasite which is very common among some other rodents of the Range Reserve, notably *Lepus* and *Sylvilagus.* Nearly all rabbits are infested with "warbles," the larvæ of a species of bot-fly, *Cuterebra* (family Oestridae). Other small mammals also are occasionally parasitized by the *Cuterebra*, but in the handling and examination of perhaps 200 or more individuals of *spectabilis* and *merriami*, we have yet to find a single case of infestation by an oestrid fly.

ABUNDANCE.

One's first impression of a well-occupied *spectabilis* area is that a large family must inhabit each den, but, as previously mentioned, we have gradually been compelled to shift from this conception to the idea of but a single animal to a mound, except when the young are present. Therefore a census of the adult kangaroo rat population can readily be made, simply by counting the mounds. Such a census affords at least a conservative estimate of the number of adult individuals occupying a given area.

The first estimates of abundance on the Range Reserve were from actual counts of dens on areas measured off for experimental fencing, and gave the figure of about two mounds to the acre. From time to time rough estimates were made on different portions of the pastures, and these checked well with the above. Later still, a careful count showed 300 mounds on approximately 160 acres (see p. 8), or 1.87 mounds per acre. Nine areas of 2 acres each, representing different environmental conditions, were later selected in different portions of the Range Reserve, and the dens accurately counted. The number of dens per 2 acres varied from none to a maximum infestation of 12, neither extreme occurring over large areas. The total number of dens was found to be 43 on the 18 acres, or an average of 2.38 dens per acre.

From all these estimates it may fairly be concluded that two mounds, or two animals, per acre is a conservative estimate for the infestation of the entire Range Reserve, with the possible exception of small areas at its upper edges, where the altitude limit of *spectabilis* is passed. It is, however, impossible to estimate the area of the State infested with kangaroo rats, for some large stretches of fine grassland show no kangaroo rats whatever, while others have more than are present on the reserve; and we have no estimates of the extent of either type.

ECONOMIC CONSIDERATIONS.

In May, 1894, Fisher found a ranchman at Willcox, Ariz., who complained more bitterly of the depredations of *spectabilis* than of those of any other mammal.

On the United States Range Reserve the food material appropriated by the kangaroo rat during good years is inappreciable. There is such an excess of forage grass produced that all the rodents together make very little difference. But with the periodic recurrence of lean years, when drought conditions are such that little or no grass grows, the effects of rodent damage not only become apparent, but may be a critical factor determining whether a given number of domestic animals can be grazed on the area (Pl. VIII, Fig. 2).

With two kangaroo rats to the acre (1,280 per square mile), there would be 64,000 animals on the 50 square miles of the Range Reserve. If each rat stores 4 pounds of grass seeds and crowns and other edible forage during the season (and in severe seasons we find that more crowns are stored than under ordinary conditions), a total of 256,000 pounds, or 128 tons, of edible forage are rendered unavailable to stock. In dry years it is probable that this amount of forage would be of critical importance. Allowing 50 pounds of food a day for each steer, the forage destroyed would be sufficient to provide for the needs of one steer for 5,120 days, or for the needs of 14 steers for one year. On a stock ranch the size of the Range Reserve this might mean the difference between success and failure.

It seems not unlikely, therefore, that during seasons of drought the banner-tailed kangaroo rat, where it is abundant on the grazing ranges of the Southwest, may be a factor of critical importance in relation to forage production and carrying capacity. It must be remembered, moreover, that the stored material consists largely of seeds, so that this loss is of greater importance than would be the case were it ordinary forage. Some of the range grasses of this region found in greatest quantity in the stored material depend in large part, under certain conditions, upon seed reproduction. Rehabilitation of a depleted range after severe drought and consequent close grazing and trampling is retarded by the heavy toll of seed taken by the kangaroo rats.

CONTROL.

Kangaroo rats may be easily eradicated by the use of the poisoned grain used for prairie-dog control by the Biological Survey and the University of Arizona Extension Service. This can be obtained by application to the State representative of the Biological Survey or to the local county agricultural agent, or may be mixed as follows:

Formula for poisoned bait.—Dissolve 1 ounce of strychnine sulphate in 1½ pints of boiling water. Add 1 heaping tablespoonful of gloss starch, previously mixed with a little cold water, and boil until a clear paste is formed. Add 1 ounce of baking soda and stir to a creamy mass. Add ½ ounce of glycerine and ¼ pint of corn sirup and stir thoroughly. Pour over 16 quarts of rolled barley and mix well until every grain is evenly coated. Allow to dry before using.

In bushel quantities use as above directed, 2 ounces of strychnine, 2 ounces of soda, 1 ounce of glycerin, 1¼ ounces of starch, 1½ quarts of boiling water, and ⅝ pint of corn sirup.

Scatter poison, when the natural food of the kangaroo rat is scarce, on clean hard places near the holes, 1 quart to 50 holes.

If powdered strychnine alkaloid is used, prepare the hot starch paste first. Then sift strychnine and baking soda, previously thoroughly mixed, into the hot starch paste and stir to a creamy mass. Proceed as in the above directions with sirup, glycerin, etc.

Use this poison within five days after mixing or retain in air-tight containers.

Caution.—All poison containers and all utensils used in the preparation of poison should be kept *plainly labeled* and *out of reach of children*, irresponsible persons, and live stock.

A spoonful of the poisoned grain scattered about the used entrances of a mound is sufficient, and prebaiting is not necessary, as with prairie dogs.

A word of caution should perhaps be offered in connection with control measures. As man has come to occupy a greater portion of the earth's surface, and as he has become more and more the master of his environment, he has inevitably disturbed the relationships of the birds and mammals about him, has upset the balance of nature. If he kills the carnivorous species because of their depredations on game and live stock he must be prepared to cope with the increased hordes of rodents which feed on vegetation and on which the carnivorous animals act as a check. If he destroys the rodents, he may remove the checks on certain noxious plants or insects. One control measure often necessitates the adoption of another.

This is not to argue against control measures, for if our harmful species were not controlled, agriculture in many sections would be impossible. Control measures, however, should be scientifically founded and applied. The indiscriminate slaughter of supposedly harmful species of birds and mammals in the guise of benefiting agriculture may do far more harm than good. Many of the species which do some harm do far more good. The exact status of each suspected species should be carefully determined through an adequate scientific investigation. If the species is condemned, sound control measures should be thoroughly applied.

In grazing districts or in areas devoted to intensive agriculture the death sentence should probably be passed on the banner-tailed kangaroo rat. It should be recalled, however, that this is the largest and one of the handsomest of all its family, and that it is one of the most characteristic and interesting of all the desert fauna; where extensive grazing or agricultural operations are not undertaken, therefore, we feel that the kangaroo rat should be let alone, unless its presence threatens infestation of valuable agricultural or grazing lands.

SUMMARY.

(1) Kangaroo rats may be separated with ease from all other mammals; the long tail and short and weak fore feet separate them from the pocket gophers; the white hip-stripe distinguishes them from the pocket mice. The decidedly larger size and the white-tipped tail separate *Dipodomys spectabilis spectabilis* and *D. deserti* from *D.*

merriami and *D. ordii*. The darker color and vividly contrasted black-and-white tail of *spectabilis* distinguish it from *deserti*.

(2) *Dipodomys s. spectabilis* occurs in the open arid country of portions of the Lower and Upper Sonoran Zones of Arizona, New Mexico, Texas, Sonora, and Chihuahua. It lives in harder soil than does *deserti*, and builds more conspicuous mounds.

(3) There is no evidence of intergradation or hybridization between *spectabilis* and *deserti*.

(4) *Dipodomys s. spectabilis* is nocturnal; it is gentle, and does not offer to bite when taken in the hand; is silent for the most part; active; somewhat sociable with its fellows, but fights in defense of its food stores; progresses chiefly by leaping; signals by a drumming or tapping on the ground with its hind feet.

(5) The breeding season of *spectabilis* begins in January and continues into August. Whether more than one litter is raised in a single season is unknown. The number of young in each litter varies from 1 to 3, averaging 2.

(6) *Dipodomys s. spectabilis* does not hibernate, but provides food stores, mostly seeds, for use during seasons when food would be otherwise unavailable. Storage in each den varies in quantity from 5 grams (about $\frac{1}{6}$ ounce) to 5,750 grams (12.67 pounds). Materials stored include several important forage plants; for example, various species of *Bouteloua* and *Aristida*, with *B. rothrockii* (crowfoot grama) the most important. Accessibility and abundance of different plants have much to do with the kinds of storage found.

(7) The dens of *spectabilis* are the most notable of all kangaroo rat dwelling places. They range from 6 inches to 4 feet in vertical height, and from 5 to 15 feet in diameter. Here the kangaroo rat has its home, shelter, and food-storage chambers. Within the den is found a tortuous network of burrows, with many storage and some nest chambers, the whole arranged so as to be two to four stories high.

(8) *Dipodomys s. spectabilis* is not of great economic significance, except locally, in ordinary seasons. During periods of extreme drought it may be of critical importance on grazing areas from the standpoint of the carrying capacity of the range.

(9) Kangaroo rats are easy to poison by following the same formula as that used by the Biological Survey for destroying prairie dogs.

(10) In many places unsuited to extensive grazing or agriculture *spectabilis* does no appreciable damage. It is one of the most interesting of all the rodents peculiar to our Southwestern deserts, and should not be molested except where it is destructive.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1092

Washington, D. C. PROFESSIONAL PAPER September 21, 1922

PEDIGREED FIBER FLAX.

By Robert L. Davis, *Assistant Plant Breeder in Fiber Investigations, Bureau of Plant Industry.*

CONTENTS.

INTRODUCTION.

The object of the work described in this bulletin has been to improve the seed used in the fiber-flax industry and particularly to develop by selection a long-stemmed flax that would increase the yield of fiber per acre.

In this work all plants that originate from the seed of a single plant or direct descendants from a single plant are known as a selection. This definition must be qualified so as not to include the progeny of a hybrid. Selections are retained only when the plants are uniform. Flax is a self-pollinated plant, and it is therefore relatively easy by means of selection and propagation of individual plants to secure strains that are uniform.

The need for selecting long-stemmed strains of fiber flax appears more obvious than that for selecting high seed-yielding strains of wheat or other grain crops. A bushel of grain is always marketable, no matter how low the yield may be, but short fiber-flax stems have very little value, because they are difficult to harvest and work up into fiber. The general crop of fiber flax produces a stem of satisfactory length not more than two years out of three; hence the need for a tall variety that will yield a good stem length even in unfavor-

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able years. Selections have been made in England, Canada, and Russia for increased stem length, but they are not yet a factor in the industry, because of the limited supply of seed.

The seed flax grown extensively in the Northwest for the production of linseed oil is more widely known in this country than fiber flax, which is grown in limited areas. Although there are intergrading forms, these varieties of seed flax are fairly distinct from the fiber varieties, and the relation between the two is quite like that between beef and dairy cattle. The short seed varieties will produce fiber under favorable moisture conditions, but they will not yield so much nor will it be fiber of so good a quality as the fiber strains. Similarly, the tall fiber-flax varieties when grown under seed-flax conditions will yield a fair quantity of seed but not so many bushels per acre as the seed-flax varieties.

A brief discussion of the fiber-flax plant and the processes of handling it to produce the fiber is introduced here for the better understanding of the crop of fiber flax and the type of plant desired.

The fiber-flax plant, under field conditions, has a single straight stem less than one-tenth of an inch thick, which grows 25 to 30 inches high and then sends out branches, forming the flower panicle. (Fig. 1.) Some idea as to the small size of the plant may be gathered from the fact that it takes nearly 600 of them to make an ounce of fiber.

Stems of small diameter produce the best quality of fiber and also the largest quantity per given weight of stalk. Seeding broadcast thickly, at the rate of 80 to 120 pounds per acre, tends to induce a growth of fine stems. Broadcasting results in stems of uniform size which are also desirable for good fiber production. From the heavy rate of seeding, about three times that practiced with seed flax, a stand is secured which shades out the weeds and in addition shades out the side branches on the flax plants, which would produce uneven places in the fiber.

The flax fibers are located in the cortex, and since they form part of the fibrovascular system of the plant most of them run nearly the full length of the stem. Some terminate in each leaf and many in each branch. Those in the branches are of practically no value for spinning. The fibers of the main stem are extracted by a series of processes: (1) retting, a decay process which loosens the fiber from the woody portions of the stem; (2) breaking, which breaks up the woody portions into small pieces; and (3) scutching, which removes the woody pieces, leaving the prepared fiber.

The flax stems are retted by either spreading in a meadow or submerging in a tank of water until bacterial action has proceeded long enough to loosen the cortex from the pith without weakening the fiber. After drying the stems thoroughly the process of breaking is

accomplished by running the straw through a number of pairs of fluted rollers which break into small pieces the woody shell surrounding the central pith. The final process of extracting the fiber, that of scutching, is accomplished by holding the fiber over a notch in the side of a wooden stall where the pieces of pith that remain clinging to it are beaten off by a revolving wheel of blunt-edged paddles.

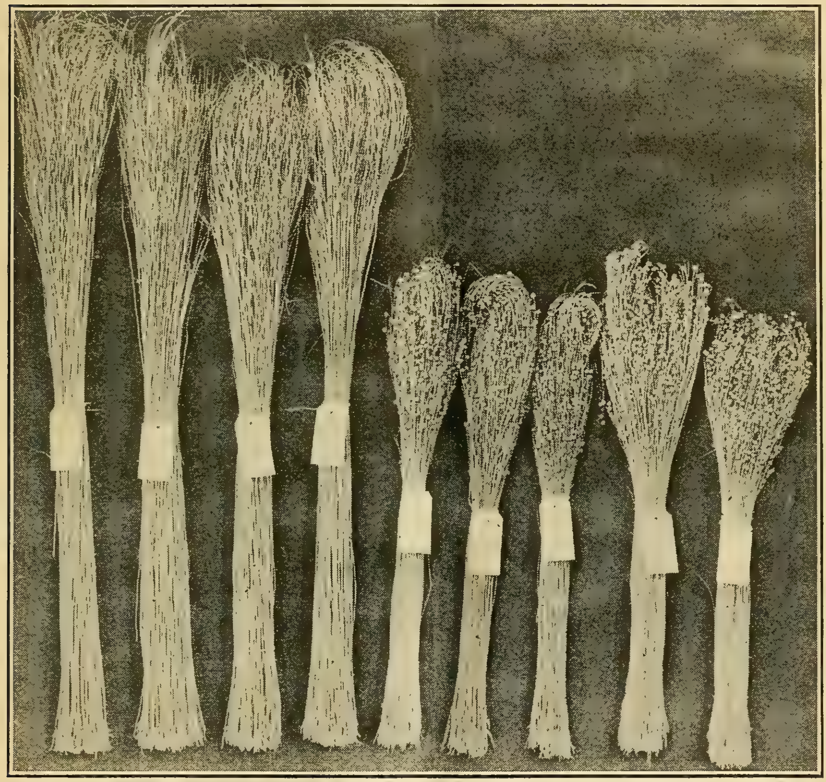

FIG. 1.—Comparison of selected and unselected fiber flax grown under the same conditions in the breeding plats in 1916. Thrashed straw of four selected strains, 35 to 37 inches high, is shown at the left. Note their similarity. The three samples in the center are unthrashed commercial Blue-Blossom Dutch fiber flax, while the two samples at the right are Minnesota No. 25, a semifiber type.

Since flax fiber runs the full length of the stem, it has been the practice in harvesting to pull it by hand. Several inches of stubble are left in the field when the flax is cut with a binder or mower, and pulling prevents this waste and also keeps the straw from being tangled. Owing to the scarcity and high cost of labor, hand pulling is becoming more and more out of the question. Two solutions of the problem are: (1) Growing a long-stemmed variety of flax which would not lose such a large percentage of its stems when cut or (2) using a machine puller. Several types of machine pullers have been

used with some success during the past three seasons on well-ripened fields of flax.

The remainder of this bulletin is devoted to the solution of the problem of developing and increasing a long-stemmed variety of fiber flax.

EARLY SELECTION WORK.

The selection work with fiber flax was begun in the United States Department of Agriculture in 1909 by Mr. A. E. Mayland. He selected several thousand plants from the fields of commercial fiber flax in Michigan. (Fig. 2.) Only where a plant was distinctly taller than the surrounding plants was it selected. Each plant was weighed

FIG. 2.—The beginning of fiber-flax selection in America. These individual plants, selected because of their superiority to others in a field of fiber flax at Pigeon, Mich., in 1909, are the ancestors of the best varieties developed by the United States Department of Agriculture.

and measured separately, and fully nine-tenths of them were discarded. Only the seeds from the very heaviest plants were saved.

In 1910 Mr. Leroy V. Crandall took up the work. Seeds from each plant retained the preceding year were sown in separate plats. The rigid selection methods with the centgener tests which had been devised at the Minnesota Agricultural Experiment Station were used. (Fig. 3.) The seeds were spaced 3 inches apart each way and covered by soil to the depth of 1 inch, so that each plant would have an equal chance to develop. Notes were taken on the selections, and if at maturity any were short or uneven they were discarded. In case any were uneven and at the same time promising for height, individual plant selections were made from them for further testing. The selections which were still regarded as promising were harvested and thrashed by hand, taking pains to keep the seeds from each plat

separate. Mr. Crandall continued the selections in this way in 1911 and 1912, the field work being carried on at Croswell, Mich., and Crookston, Minn.

In 1913 Mr. Frank C. Miles took up the work and continued it until the spring of 1917. As a basic stock for selection, strains which had been developed by Mr. Crandall were used, and material was added from imported seed as well as from the commercial fiber-flax fields of Michigan and Oregon. Selection plats were grown by Mr. Miles on the Potomac Flats near Washington, D. C., at Yale, Mich., on the grounds of the Northwestern School of Agriculture, Crookston, Minn., and at the Oregon Agricultural College, Corvallis, Oreg. The most important work was carried on at Yale. Improved strains decidedly superior to commercial strains were developed and attempts made to increase the seed, but in three seasons this work was interfered with by disastrous storms at Yale and at Crookston, which practically destroyed the increase plats.

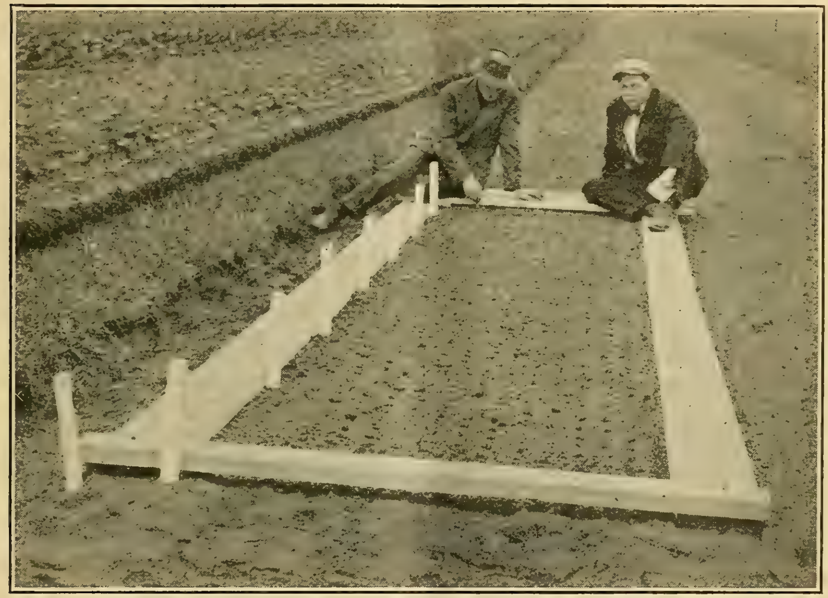

FIG. 3.—Planting the first plat of fiber-flax selections. Holes are made just 3 inches apart and 1 inch deep. One seed is planted in each hole. The stakes mark the number of the parent plant. Croswell, Mich., May 10, 1910.

The flax planted on the Potomac Flats at the Arlington Experimental Farm, Va., in 1913 and 1914 made a satisfactory growth and flowered, but it produced very few seeds. Work at this point was therefore discontinued.

A number of tall plants were grown in the greenhouses at Washington, D. C., during the winter of 1913, and crosses were made between the more promising ones. These crosses were grown to the

third generation, but they did not result in strains of value. This negative result may perhaps be due to the fact that only a limited number of crosses were made. The crosses between selections from the Blue-Blossom Dutch and White-Blossom Dutch varieties resulted in strains that were intermediate in resistance to flax wilt. The flax under greenhouse conditions took four and one-half to five months to mature and made an abnormal growth. Some of the plants reached a height of 170 centimeters ($5\frac{1}{2}$ feet), so that it was found necessary to support them on wires.

It was found impracticable to handle large numbers of selections with the centgener method, because of the time consumed in planting seeds one at a time, and flax selections after 1914 were sown in drill rows. Uniformity of growth conditions similar to those of the centgener method was secured in 1918 by thinning out the rows to one plant to the inch.

ELIMINATION OF POORER SELECTIONS.

Very early in the work those selections that were most promising were sown on a larger scale than the others, so that in 1914 enough seed had been secured from the one then considered the best to sow it at frequent intervals throughout the experimental plats. From year to year additional selections were made, as in the year 1909, and wherever one of them growing next to this standard selection has been judged inferior it has been discarded. This standard selection has been called the "check," as it acts as a check on the soil conditions. The check serves the same purpose as a ruler placed alongside a plant and is in one respect better than a ruler, for it measures the soil conditions by growing tall where the soil is rich and short where the soil is poor.

As more and more of the selections were discarded, those retained became more and more like each other, because all of them possessed in some degree each of the desired characters. (See the selections shown in Fig. 1.) Thus, it became necessary to study a larger number of characters as a means of elimination of the poorer selections. In addition to length of stem and stem weight, the following characters were added: Strength of fiber per individual stem, the amount of basal branching, the vitality of seed, and resistance to disease. The check selection has furnished a ready means of comparison between the different selections for all these characters. Data were rapidly accumulated on the check, as it was sown in many duplicate plats and measured extensively.

Strength tests were begun in 1912, and during the years 1913 to 1917 hundreds of strength tests were made under the direction of Mr. Frank C. Miles. In this way many inferior selections were eliminated. It was found that the middle portion of the stem

was stronger and less likely to vary than either the basal portion or the top; so this portion was always used in making the strength tests. The stem diameter was measured at a point in the middle of the portion chosen for the test, and if several stems were of equal breaking strength the one with the smallest stem diameter was considered the strongest. In order automatically to determine the stems with the greatest strength per stem diameter, the practice of dividing the breaking strain by the diameter was adopted in 1919. This gives the strength per millimeter of diameter. The manner of making the strength tests is as follows: The stems are water retted at a uniform temperature so as to loosen from the wood of the stem the cortex in which the fibers are located. A piece 15 centimeters long is cut from the center of the stem chosen for the test. The wood is broken along the middle 2 to 3 centi-

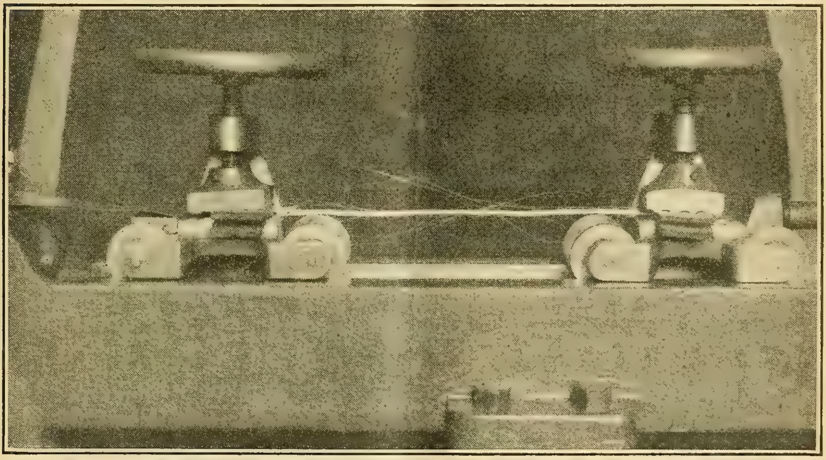

FIG. 4.—Completion of a strength test. Good fiber is indicated by breaking at several points and snapping away from the stem.

meters of this piece by rolling a glass tube over the stem without breaking the fibers. The pieces of wood are removed by working the stem with the fingers, and nothing is left but the fibers and those portions of the cortex which remain clinging to them. The strength tester (Fig. 4) is a horizontal machine with two pairs of jaws, between which the ends of the individual piece of stem are fastened. One jaw is rigid and the other, which is movable, exerts a pull on the fibers which is registered in kilos to the tenth place. This figure is known as the breaking strain.

Records for 1917 and 1918 show that the extent of basal branching is an inherited character, and it has therefore served as an eliminator. Seed-flax varieties have as a rule four or more basal branches, and the unselected fiber flaxes have two to four. The quality of fiber is poorest in the White-Blossom Dutch variety, the fiber flax with the largest

number of basal branches, and the selection work has always aimed to reduce this branching habit. The manner of branching can best be studied in open drill rows where the plants, thinned down to one to the inch, are not crowded and can develop normally. In open drill rows the check selection never develops more than two basal branches, and with more than half of the plants it has none at all. Any selection having more than two basal branches was discarded.

Seed vitality received more attention as the work progressed. In addition to making germination tests and taking notes on the stand secured in the field, a study was made of the number of seeds per boll of all promising selections. The number of seeds per boll when complete fertilization occurs is 10. This number is rarely approached under field conditions. The data of 1919 and 1920 confirm the earlier work. The average number of seeds per boll is an inherited character directly associated with the vitality of the seed. For example, Selection 1923, with the best vitality of seed, has a high count of seeds per boll, and Selection 1812, with poor vitality of seed, has a low count of seeds per boll. Hence, all selections having a decidedly low count of seeds per boll were eliminated unless the count for the check selection, grown in the same part of the field, also ran very low.

In the years 1914 and 1915 marked differences in resistance to wilt were noted in fiber-flax selections when a natural survival of the more resistant selections took place. The check, Selection No. 5, was at this time superior to most of the others in resistance to wilt. In 1919 the selection plat at Croswell, Mich., was planted on soil where flax stems had been previously spread. All selections from the White-Blossom Dutch variety were completely destroyed by flax wilt, and not more than one-fourth of the plants among the selections from the Blue-Blossom Dutch variety, the other commercial fiber flax, survived. The check selection, planted in every other row, was more than 85 per cent resistant. Corroboration of the results was secured in 1920 through the cooperation of the Office of Cereal Investigations of the Bureau of Plant Industry. Plats were sown with seeds furnished from the selection plats of fiber flax by Mr. J. C. Brinsmade, jr., at Mandan and by Mr. W. E. Brentzel at Fargo, N. Dak. In Mandan the check, Selection No. 5, was over 80 per cent resistant to wilt, while the Blue-Blossom Dutch variety was 21 per cent and the White-Blossom Dutch only 1 per cent resistant. At Fargo, Selection No. 5 compared favorably with the most resistant seed flaxes in both resistance to wilt and seed yield. At both places the order of resistance of the different fiber-flax selections was approximately the same as that obtained in the selection plat in Michigan; those selections which were more resistant in Michigan were also the ones most resistant in North Dakota. This work makes it possible to eliminate

all except a very few selections which show promise of wilt resistance. The fact worthy of special note is that wilt resistance is not peculiar to a restricted locality, since fiber-flax selections proved to be resistant in North Dakota as well as in Michigan.

By the year 1918 the work of elimination had brought the number of selections still being considered down to 25 or 30, all of which were tall. It was not easy to distinguish between them, and it became necessary to use the check system more rigidly than before. The check rows were sown closer together, so that not more than two varieties were grown between them. The distance between the checks was about one-twentieth the length of the row, because if farther apart the soil variation may be too great for the check to indicate accurately whether the soil between it and the next check is good or poor. The rows were increased in length from 1 to 10 rods each, because a larger plat gives more accurate results. The plants were thinned to one to the inch, in order that there might be the same number of plants in each row and each selection might have the same chance to develop. Duplicate sowings in different parts of the field were made of each selection.

Since only two varieties or selections were planted between checks, each one of them had the best selection or check growing beside it. This made it possible for notes to be taken at sight in comparing them for resistance to disease, uniformity of growth, and resistance to lodging. If a selection had more dead straws than the adjacent check row, it was considered inferior to it in disease resistance. If it lodged or bent over from rain or heavy dew more than the check row, it was marked as not resistant to lodging. If the stand was very irregular and the stand of the check growing alongside was all right, it was graded as having a low vitality.

COMPARING WITH THE CHECK BY PERCENTAGES.

For more accurate comparison of stem weights, seed weights, stem lengths, number of seeds per plant, and other measurable characters, these data have been reduced to percentages, a method adopted in the plant-breeding work in Scandinavia.[1]

These percentages have been called by Prof. Frank Spragg the coefficient of yield.[2] If we have Selection A, which yields three-fourths as much straw as the average of the check rows on each side, it is given a value of 75 per cent. If the weight of the straw of Selection B is nine-tenths that of the adjacent checks, it is given a value

[1] Newman, L. H. Plant Breeding in Scandinavia, 193 p., 63 fig. Ottawa, Ont., 1912. Literature cited, p. 188–193.

[2] Spragg, Frank A. The coefficient of yield. *In* Journ. Amer. Soc. Agron., v. 12, no. 5, p. 168–174. 1920.

of 90 per cent. It is assumed in all cases that the check row responds to the soil conditions in the same way as the other selections. If the soil is poor the growth of both will be poor, and if the soil is rich the growth of both will be good. If these two strains A and B, grown in different parts of the field, were to be compared directly as to the actual straw weights, the poorer one might, because of better soil conditions, be apparently the better straw yielder. The use of the check prevents such a mistake, as the check rows measure the soil conditions and when percentages are calculated give the true relation between these selections, which is as 75 to 90 on straw weight.

The percentages assigned to the different selections can be reduced to straw weights as follows: Since Selection A yields 75 per cent as much as the check row alongside of it, we assume that it would yield 75 per cent as much as the average of all the check rows sown throughout the field. If the average yield in straw per acre of all the check rows is 2 tons, then, because Selection A is three-fourths as good as the check nearest to it, it is assumed that it would yield three-fourths as much if sown in all places that the checks were sown, or $1\frac{1}{2}$ tons per acre. This gives what may be termed the corrected straw yield, as by means of the checks correction for soil variations has been made. In the same manner, corrected seed weight, corrected stem length, and corrected values for any number of other characters may be found.

USING THE SCORE CARD FOR THE ELIMINATION OF THE POORER SELECTIONS.

Since all the characters are not of equal importance, a score card has been devised to record the proper values for them, so that the sum total of the good and the bad points of each selection may be expressed in one figure. The following characters have been considered as sufficiently important to be used in the score card: Weight of thrashed straw, weight of seed, length of stem to the first branch, resistance to lodging, resistance to disease, and strength of fiber. When available the weight of fiber will take the place of the weight of the thrashed straw.

Resistance to lodging has been given a value of 5 per cent, because weather that would cause lodging might be expected about 1 year out of 10, and since the flax that is resistant to lodging could only be expected to stand up about half of these times, it would have an advantage of about 5 per cent over the other strains.

Resistance to disease has been given a value of 4 per cent, because loss from diseases has been a less serious factor with fiber flax than loss due to lodging.

There is left 91 per cent to be divided among weight of thrashed stems, length of stem to first branch, seed yield, and strength of fiber.

In order to cover the additional expenses of growing a crop of fiber flax it must bring in more money than a crop of seed flax. The heavy rate of sowing requires 1 bushel more of seed per acre. When pulled by hand the extra cost is $10 to $12 per acre. It is thrashed in a special manner at extra expense to keep the straw straight and unbroken. The seed yield per acre is about 3 bushels less than where the flax in the same locality is sown for seed production. Since drought is more likely to stunt the growth of the stems than to affect the seed yield materially, there is more risk involved in growing a crop of flax for fiber. Hence, there are extra expenses in seeding, harvesting, and thrashing; a diminished seed yield; and an extra risk involved in growing the crop. It is estimated that in order to cover these items the straw of a crop of flax must be three times as valuable as its seed, and the values assigned in the score card are in the ratio of 3 to 1.

Since one of the principal objects of the selection work with fiber flax has been to secure increased stem length, it has been thought best to assign to it a value slightly more than that assigned to seed yield. This value, about one-third that for weight of thrashed stems, is based in part on reason, for it has been common practice in times past to offer a premium of one-sixth to one-third for a ton of stems of extra length. In applying this value only the amount of superiority in stem length has been considered; the check selection is superior by 16.31 centimeters ($6\frac{1}{2}$ inches) to Blue-Blossom Dutch, the common commercial fiber flax, while Selection No. 1923 with only half this superiority scores only half as much as the check on this character.

Strength of fiber is regarded by experts as of first importance in judging flax fiber. The strong fiber can be spun into much finer threads than fiber that is of inferior strength. The price for fiber of superior quality is frequently one-sixth to one-half more than that of medium grade. Strength of fiber determines to a considerable extent the range of prices, and it has been assigned an intermediate value of one-third. It is assumed then that strength of fiber is one-third as important as weight of fiber, and when weight of fiber is not available weight of thrashed straw takes its place.

In accordance with the preceding line of thought, the remaining 91 per cent has been divided, resulting in the completed list of values shown in Table 1.

TABLE 1.—*Relative values of characters used in comparing strains of fiber flax.*

Characters compared.	Assigned value.	Characters compared.	Assigned value.
	Per cent.		*Per cent.*
Weight of thrashed stems	45	Resistance to lodging	5
Length of stem to first branch	16	Resistance to disease (flax wilt)	4
Strength of fiber	15		
Weight of seed	15	Total	100

The score card has been applied to 24 selections and to White-Blossom Dutch and Blue-Blossom Dutch, two unselected varieties of fiber flax. (Table 2.) Without exception all the selections are superior in stem length to the unselected commercial varieties. The latter are chiefly superior in seed yield only and score a total percentage lower than all except one selection which has a low yield of thrashed straw.

TABLE 2.—*Score card applied to 24 tall fiber-flax selections and 2 varieties of commercial fiber flax.*

[Based on data for the years 1914 to 1920, inclusive.]

Number or name.	Weight of thrashed straw.		Weight of seed.		Length of stem.		Breaking strain.		Resistance to—		Total score.
	Per rod row.	Score.	Per rod row.	Score.	To first branch.	Score.	Average per millimeter of diameter.	Score.	Lodging.	Flax wilt.	
	Grams.	*Per cent.*	*Grams.*	*Per cent.*	*Centimeters.*	*Per cent.*	*Kilograms.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1905	568	45	98.98	15	65.91	16	2.77	15	2	4	97
1901	577	45.7	84.6	12.68	69.2	19.2	....	15	2	0	94.58
1903	567.5	45	97.6	14.68	65.9	16	[a] 3.35	18.7	3	4	101.29
1904	641	50.16	98.6	14.81	64.5	14.6	1.74	9.43	0	1	90
1906	543	43	88.2	13.25	64.8	14.9	2.49	13.5	0	0	84.65
1907	509	40.3	85.6	12.87	65.7	15.6	[a] 2.57	13.91	0	0	82.65
1908	517	40.9	90.5	13.6	67.2	17.26	[a] 2.49	13.5	0	0	85.26
1910	640	50.8	90.3	13.58	64.9	15	2.22	12.01	0	4	95.39
1911	530	41.5	69.3	10.40	67.5	17.56	1.96	10.60	2	2.5	84.56
1812	681.5	54	99.7	14.96	66.55	16.60	2.32	12.56	2	2	102.12
1914	623	49.4	93.2	14	67.6	17.66	[a] 2.83	15.32	0	2	98.38
1915	515	40.8	83.7	12.59	67.7	17.76	2.19	11.87	0	1	84.02
1919	531	42	108.9	16.37	66.3	16.40	2.04	11.05	0	4	89.82
1920	546	43.4	67.2	10.10	67.25	17.30	[a] 2.08	11.26	0	1	86.48
1921	525	41.6	86.8	13.03	66.1	16.20	2.52	13.65	0	1	85.48
1922	400	31.7	91	13.69	62.35	12.52	[a] 2.32	12.56	2	0	72.47
1923	527	41.8	121.6	18.25	57.5	7.75	2.72	14.76	5	2	89.56
1924	497	39.4	95	14.28	64	14.13	2.18	11.80	0	1	79.61
1925	522	41.3	107.2	16.1	65.4	15.66	1.45	7.85	0	2	83.91
1926	607	48.1	110.6	16.61	59.5	9.51	2.90	15.70	2	2	93.92
1927	518	41.2	77.1	11.60	60.6	10.78	2.07	11.60	5	1	75.78
1928	490.5	38.9	74.6	11.20	58.4	8.62	[a] 3.58	19.37	0	1	79.09
1929	520	41.3	112.2	16.85	60.2	10.39	1.60	8.66	2	1	80.2
1931	597	47.2	144.2	21.7	61.7	11.86	[a] 1.69	9.2	2	0	88.76
Blue-Blossom Dutch.	449	35.6	133.3	20.5	49.6	0	[a] 1.94	10.5	5	0	72.6
White-Blossom Dutch.	547	96.5	149.4	22.4	49.25	0	[a] 1.35	7.35	0	0	72.75

[a] Record of only one year. Where no record is available the breaking-strain score of the check is inserted.

The 11 selections which the score card places at the top of the list (Table 3) may be classified in three groups, according to whether they appear superior, equal, or inferior to the check.

TABLE 3.—*Summary of 2 to 5 year averages, comparing the 10 best selections with strains of commercial fiber flax.*

Number or name.	Yield per acre.			Height.		Breaking strength per 1/16 inch of diameter.	Origin.
	Straw.		Seed.	Total.	To first branch.		
	Thrashed.	Unthrashed.					
	Lbs.	*Lbs.*	*Bu.*	*Inches.*	*Inches.*	*Lbs.*	
1812	1,490	1,972	4.86	34.8	26.3	5.07	In 1909, from fields of Blue-Blossom Dutch, Sanilac County, Mich.
1903	1,489	1,705	4.84	38.1	26.4	a 7.40	Do.
1914	1,361	1,762	4.64	35.4	27.1	a 6.20	Do.
1931	1,305	1,964	7.17	36.0	24.7	3.71	From North Dakota, No. 155, at Fargo, N. Dak.
Saginaw (1905)	1,242	1,608	4.95	37.8	26.4	6.05	In 1909, from fields of Blue-Blossom Dutch, Sanilac County, Mich.
1910	1,400	1,812	4.48	36.5	25.9	4.86	Do.
1901	1,262	1,610	4.18	38.7	27.7	No record.	English pedigreed, imported from Australia in 1916.
1926	1,328	1,758	5.48	35.6	23.7	6.35	In 1909, from fields of Blue-Blossom Dutch, Sanilac County, Mich.
1904	1,400	1,970	4.88	37.4	25.4	1.74	Do.
1919	1,172	1,494	5.40	42.6	26.6	4.46	Do.
Commercial unimproved fiber flax from Holland:							
Blue-Blossom Dutch	983	1,333	6.62	26.5	19.6	a 4.23	Imported in 1905.
White-Blossom Dutch	1,186	1,630	7.42	32.3	20.0	a 2.96	Imported in 1917.

a Record of only one year. Where no record is available the breaking-strain score of the check is inserted.

Of those that appear superior to the check, Selection Nos. 1812, 1903, and 1914, only No. 1914 can be considered, for Selection Nos. 1812 and 1903 have a low seed vitality. Selection No. 1914 compares favorably with the check; it has good seed vitality and is somewhat taller; it has fine stems and very little basal branching. The advantage appears, however, to lie with the check, for Selection No. 1914 is more inclined to lodge than the check, and its resistance to wilt is not well established.

The second group, consisting of those that appear about equal to the check, contains Selection Nos. 1910, 1901, and 1926. All of these grade under the check on total score, but appear equal to the check when the percentages allotted to resistance to wilt and lodging are subtracted. Selection No. 1910 is very resistant to wilt, but has coarse stems and develops more basal branching than any of the other tall selections. Selection No. 1901 comes nearest to the check in this group, because of its extra-long stems, but it has a low seed vitality and its stems are slightly coarser than those of the check. Selection No. 1926 has very fine stems, even finer than those of the Blue-Blos-

som Dutch variety, which is 6 inches shorter, but it also has a low seed vitality and is inferior to the check in stem length.

The third group, consisting of Selection Nos. 1904, 1919, 1923, and 1931, appears inferior to the check but is analyzed in order to make sure that no one of them is worthy of seed increase. Selection No. 1904 is the most promising one of this group in stem weight; it is, however, inferior to the check in stem length, and its resistance to wilt is low. Selection No. 1919 is very resistant to wilt but its stems are coarse; furthermore, when resistance to disease is not considered it grades distinctly lower than the check. Selection No. 1923 is noticeably inferior to the check in length of stem and is not deserving of general distribution; it is, however, high in stem weight in spite of its relatively short stems and may be suited to areas where very tall growth is not desired to the exclusion of high seed yield. Selection No. 1931 is too low in wilt resistance to warrant seed increase and distribution.

It is concluded from a study of the score card and additional characters which are not used in the score card that Selection No. 1905 is the most desirable one for seed increase. Its strength of fiber is not surpassed by any selection of which more than one year's record is available. It is superior in resistance to wilt to all except two of the eleven best selections, and these are undesirable because of coarse stems and the extent of basal branching. Out of the five selections that are its equal or superior in straw weight, two have a low seed vitality, two are inferior in stem length and very low in wilt resistance, and the remaining selection is more inclined to lodge than the check.

It is recognized that the percentages alloted in this score card are more or less arbitrary and that, furthermore, they should be altered to suit the convenience of the plant breeder. If, for instance, a special attempt is made to select for resistance to lodging, it is thought that a much higher percentage should be assigned to that factor, so that it would be a determining one in deciding on the best selection.

The chief difficulty in the accurate working of the score card is that the systems of planting as well as the places where the sowings were made varied widely from year to year; also, the records on all the selections are not complete for the entire 7-year period. Efforts are made to overcome these difficulties by comparison with the check which is planted each year in many duplicate plats.

IMPROVEMENT BY CROSS-POLLINATION.

An attempt has been made, beginning in 1918 and continuing up to the present time, to combine the desirable qualities of several of the best selections by cross-pollination. Third-generation progenies of

several of these crosses give promise of distinct improvement. The most definite results secured were from a cross between a tall blue-flowered fiber flax and a short pink-flowered seed-flax type. The object of the cross was to secure a tall pink-flowered fiber flax which would be distinct from the ordinary blue or white flowered types.

The blue-flowered parent, Selection No. 1831, originated as a single plant selected for height in 1910 and has shown a superiority in stem

FIG. 5.—Pink-flowered flax and parent strains. Blue-Blossom Dutch fiber flax, 110 centimeters high (on the left); pink-flowered hybrid, third generation, 90 centimeters high (in the center); pink-flowered seed flax, 65 centimeters high (on the right).

length over unselected fiber flaxes for a period of five years. It has two, rarely four, basal branches and matures in 85 to 90 days. The average total height is 100 centimeters.

The pink-flowered parent came from a single plant found as a mutation in a field of tall blue-blossom fiber flax which had been selected for height. In a field with an estimated number of 800,000 plants only one pink-flowered plant was discovered. It has four to

eight basal branches and reaches maturity in 65 to 75 days. Under favorable conditions it does not grow more than 60 to 65 centimeters in total height. This pink-flowered flax is a form of *Linum usitatissimum* L. and is distinctly different from the red-flowered ornamental known as *Linum grandiflorum rubrum* Desfl.

The method of selection followed in this cross has been to rogue out all short pink-flowered flax plants in the second generation and to select all tall pink flax plants. The rest of the hybrid seed has been lumped together. In order to secure a good type it is necessary to select so as to eliminate the low count of seeds per boll, the short stem length, and the large extent of basal branching, all features which are characteristic of the pink-flowered parent. One of the tall pink flaxes selected in the second generation has bred true in the third and fourth generations and is almost half again as tall as the pink-flowered parent. (Fig. 5.) It has the reduced branching habit and late maturity of the tall blue-flowered parent combined with the pink flower color of the short parent. Since all commercial flaxes have blossoms of either blue or white, the color of this tall pink-flowered selection will serve to identify it in the field and simplify crop inspection.

INSTRUMENTS DEVISED FOR USE IN BREEDING FLAX.

Plant-breeder's forceps.—The use of a plant-breeder's forceps (Fig. 6) facilitates the work of removing the stamens. This is worn on the finger when in use. The brass ring to which the short arm is soldered is cut obliquely, so that the movement of the first joint of the forefinger will be unrestricted. The pressure of the thumb on the forefinger closes the tip against the stamen. In order that the tips may point at right angles to the direction at which the pressure is exerted, the arms of the forceps are bent. Mr. William Snyder, formerly of the Porto Rico Agricultural Experiment Station at Mayaguez, P. R., assisted materially in designing this instrument.

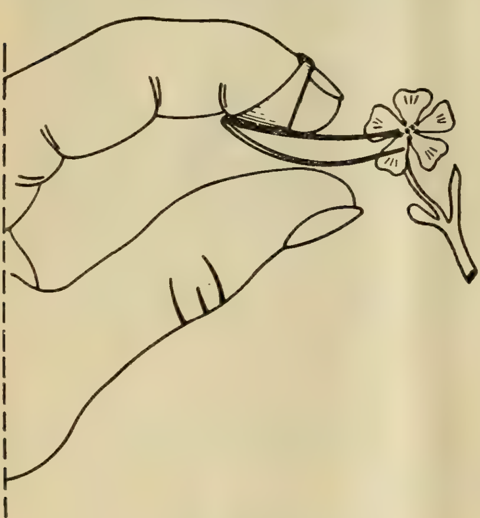

FIG. 6.—Plant-breeder's forceps.

Plant-breeder's calipers.—For measuring diameters of small plant stems the plant-breeder's calipers (Fig. 7) have been found a source of convenience with flax. The stem to be measured is inserted in the notch *N*. The scale magnifies the stem diameter 20 times, because it is 20 times as far as the stem notch from the place where the pointer is pivoted.

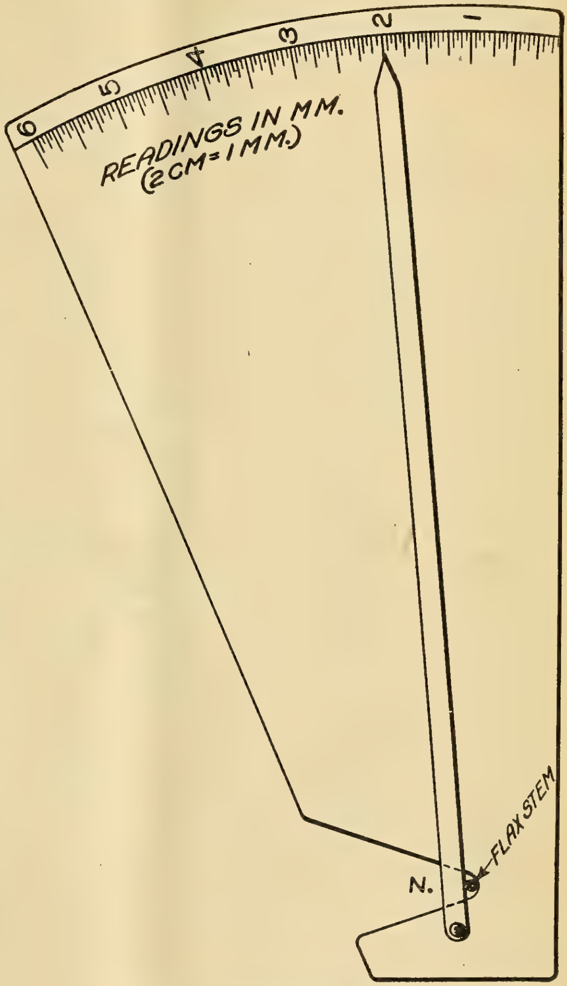

FIG. 7.—Plant-breeder's calipers.

Plant-breeder's envelope.—These envelopes (Fig. 8) are made on a sewing machine by stitching together two sheets of oiled paper. An unstitched portion is left at the base. This is slit up the middle, and at the apex of the slit a hole is cut to fit the stem of the emasculated flower. After the stem has been inserted in the envelope the unstitched part at one side of the slit is folded at right angles and that on the other side at an angle of 45° to the base of the envelope. At the point where these folded parts overlap they are fastened with an ordinary dress snap fastener. These envelopes can not come unglued, and they have the additional advantages of being light in weight and moisture proof.

COMMERCIAL TEST OF PEDIGREED FIBER-FLAX STRAINS.

Whether the improvement be secured through cross-pollination or by straight selection, it is necessary that the results obtained in the experimental plats be tested on a commercial scale in order to be

sure that the strains are good enough for distribution. Four of the most promising of the strains of selected fiber flax were sown in a field alongside some Blue-Blossom Dutch fiber flax, the variety commonly grown for fiber both in the United States and in Canada. There was a superiority of at least 6 inches in height and in the length of fiber for all the selected flaxes over the unselected Blue-Blossom Dutch flax. The Saginaw variety, with an extra length of 8 inches, yielded 30 per cent more straw per acre than the Blue-Blossom Dutch; besides, since the stems were freer from flax wilt, it yielded a better quality of fiber. Under actual field conditions the pedigreed fiber flax yielded one-third more fiber per acre than the commercial variety, Blue-Blossom Dutch flax, and this more than outweighs the only important advantage the commercial flax has over it—that of producing one-fifth more seed. (Fig. 9.)

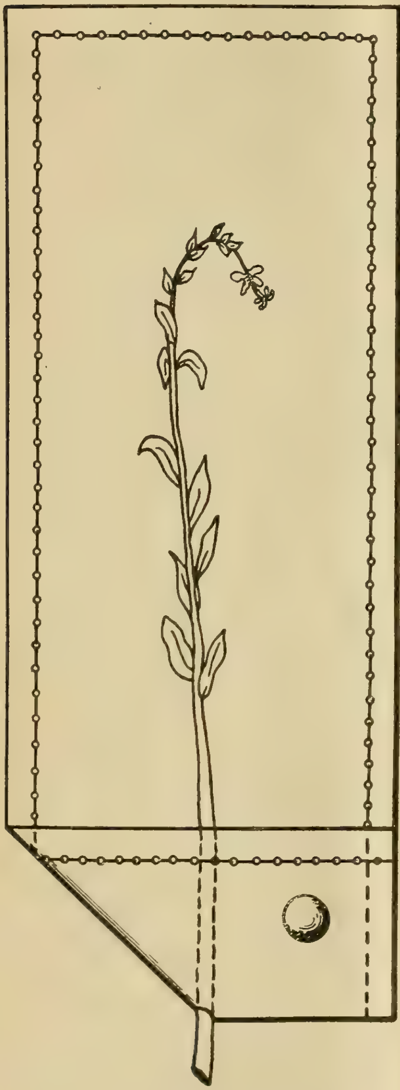

FIG. 8.—Plant-breeder's envelope.

The results of a direct comparison of these two varieties of flax are shown in Table 4.

Since this pedigreed fiber flax, grown in this country for the last 12 years, maintains the superiority shown in Table 4 over seeds freshly imported from Holland and Russia, it would not appear necessary to import fiber flax for seeding purposes, provided proper care is taken of the seed produced in this country. In this connection it may be stated that observations during the last 10 years, both in experimental-plat and commercial sowings do not show that imported seeds have any advantage over those grown in this country.

TABLE 4.—*Results of a test of flax made at Croswell, Mich., in 1919.*

Variety.	Total height.	Area.	Yield per acre.		
			Seed.	Unthrashed straw.	Fiber.
	Inches.	*Acres.*	*Bushels.*	*Tons.*	*Pounds.*
Blue-Blossom Dutch	30.0	6.0	8.0	1.42	195.44
Saginaw	38.2	1.4	6.6	1.85	293.00

Of the three other selections tested, remarkable differences were shown in the yield and quality of the fiber. One selection which had consistently yielded a larger tonnage of straw than the Saginaw variety produced one-fourth less fiber per acre, because it yielded a low percentage of fiber. Selection Nos. 1927, 1931, and 1919 not only produced less fiber than the Saginaw variety but produced fiber of a coarser quality. It is evident that for securing accurate testing of selected fiber-flax strains straw weights are not dependable. More satisfactory results could be secured from actual yields of fiber if complete data for this character were available.

INCREASING THE QUANTITY OF PEDIGREED SEEDS.

Having decided on the best strain of fiber flax, the next step is to increase the seed as rapidly as possible. From 300 to 500 acres are required to operate a small flax mill efficiently, and in order to become a factor in the commercial field it is necessary that a strain of pedigreed fiber flax reach the point where there is enough seed to sow this area, or from 500 to 700 bushels. If a start is made with an ounce of seed and the flax is sown at the ordinary rate for fiber, 1½ bushels per acre, it is estimated that at the end of 4 years, with good crops each year, there would be not much more than a bushel produced, and that it would take 10 to 15 years to produce the required quantity. There are two ways of speeding up seed production, one by thin rates of seeding and the other by making two sowings the same year.

Increasing the yield by thin rates of seeding was carried out as follows: Up to the time when there were about 5 bushels of seed it was sown at the rate of 4½ pounds per acre in 28-inch drill rows and cultivated at frequent intervals. This was done in 1918 at East Lansing, Mich. It paid, for from 10 pounds of seed 420 pounds were obtained. By the usual method, sowing by broadcasting at the rate of 84 pounds per acre, not more than 60 pounds could have been harvested. Since with as much as 5 bushels of seed this extremely thin method of sowing is cumbersome and expensive because of the large

acreage required, it was more practical after this time to follow the method used with seed flax, that of sowing in 7-inch drill rows at the rate of about one-half bushel per acre.

FIG. 9.—Fiber of pedigreed fiber flax (at left) compared with that of the Blue-Blossom Dutch variety (at right).

If by a thin rate of seeding 40 seeds could be obtained for each one planted, then each harvest season would multiply the number of pounds of seed by 40. From two harvest seasons in a year the number of seeds started with could be multiplied by 40 twice, or by 40 and again by 40, which is 1,600 times. It is necessary to grow flax as a winter crop in a southern climate in order to secure two harvests the same year, and Porto Rico gave promise of being a suitable place.

In 1917 a small trial plat of flax as a spring crop in Porto Rico gave a splendid growth, and in the spring of 1918 an increase of 26 times was secured, but owing to delay in the shipment the seed arrived too late for spring planting in Michigan. The idea was then conceived of planting a fall crop in Porto Rico, so as to allow time enough for the seed to be shipped north in the spring and arrive in due season for sowing. The flax seed which had been increased 42 times in the summer of 1918 at East Lansing was planted the last

week in October at Mayaguez, P. R. An increase of only 4 times was secured, because the winter dry season caught the flax early in December, before it had completed its growth. An increase of nearly 200 times in one year from two of the selections was obtained, so that there was nearly a bushel of each, or enough for a commercial test in 1919. Flax was again grown as a winter crop in Porto Rico in 1919 and the seeding made a month earlier, in order that it might make most of its growth in advance of the dry season. The torrential downpours of the terminating rainy season drowned most of the seed and the young plants and resulted in a poor growth in the rest of the stand, so that less seed was harvested than was put in the ground. Further trials were then made in other localities.

SEED INCREASE BY GROWING TWO CROPS A YEAR.

On November 5, 1920, 2½ bushels of pedigreed fiber-flax seed which had been harvested the preceding August at East Lansing, Mich., was sown near Fairhope, Ala., 2½ miles east of Mobile Bay. The winter was mild and no temperature below 28° F. was experienced. The flax grew to a height of 6 inches by December 15 and then lay practically dormant until early in February. From that time it made a rapid growth and at maturity on April 20 had reached a total height of 3 feet. From the 2½ bushels sown about 20 bushels of clean seed was secured. The flax was thrashed on May 3 and resown in Michigan on May 18. While normally an increase of only 6 to 25 times is expected with flax, by means of the two-crops-a-year method this flax was increased 200 times. Observations do not show that there is any loss of vitality in the seed from flax which has been grown twice the same year and then replanted shortly after the second harvest.

The results from a similar sowing of the fiber flax at Paradis, La., were also favorable from the experimental viewpoint and demonstrated that under mild winter conditions a second crop of flax can be matured in the South so as to increase the supply of seed of pedigreed flax varieties.

SUMMARY.

The object of the work described in this bulletin has been to develop improved strains of fiber flax.

Parent plants for beginning the work of breeding fiber flax were first selected in the commercial flax fields of eastern Michigan in 1909.

The progeny of these selected plants was carefully bred by elimination of all except the best types through several successive generations.

The method of selection now used is based on a comparison by percentages of the various characters regarded as important and similar characters of the best strain used as a check.

In a semicommercial test the pedigreed strains proved to be superior to commercial fiber flax.

The supply of seed of the best pedigreed strains has been increased by growing two crops in one year.

Efforts are now being made to combine the desirable characters of different strains by cross-pollination. A special score card and special instruments for cross-pollinating and for measuring flax have been devised.

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THE GIPSY MOTH ON CRANBERRY BOGS.

By Charles W. Minott,

Gipsy Moth Assistant, Gipsy Moth and Brown-tail Moth Investigations, Bureau of Entomology.

CONTENTS.

INTRODUCTION.

While the gipsy moth (*Porthetria dispar* L.) has been in Massachusetts since 1868, that section of the State in which the cranberry industry is established was nearly immune from the ravages of this insect until 1913. About this time, however, owing to favorable conditions, the infestation increased very rapidly in the southeastern part of the State, and occasional complaints were heard regarding injury to cranberry bogs in certain sections of Bristol, Barnstable, and Plymouth Counties. These conditions, and the importance of the cranberry industry, were sufficient causes to warrant a study of the habits of the gipsy moth on this new food plant. Under the direction of A. F. Burgess, in charge of moth work in New England, the writer began a study of the problem in 1916, the results of which are recorded in this bulletin, together with suggestions in

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regard to methods of control which may be adopted in cases where this pest becomes a menace to cranberry bogs.[1]

ARTIFICIAL CRANBERRY BOGS.

The locations in which cranberries may be grown vary considerably in regard to natural conditions. In Massachusetts, the State with which this investigation more particularly deals and in which more than half of the total crop is produced, the cultivated, or artificial, bogs are constructed in locations where, perhaps, the cranberry once grew naturally, but not necessarily so. They are, however, always located in natural depressions of the land, varying in size from less than an acre to more than 100 acres, in natural swamps or bogs, in which the water table is constantly near the surface of the soil. To protect the plants against damage from frost or against insect injury, it has been found desirable to provide for flowing the bogs with water. Where this can be done the bog is called a wet bog; where not, a dry bog. Each has its advantages; but as a rule wet bogs are preferred.

HOW BOGS BECOME INFESTED WITH GIPSY MOTHS.

The topography of the cranberry-producing sections of Massachusetts is characteristic of the glacial drift of Cape Cod. It is broken by low rolling hills, interspersed with bogs, ponds, and meadows. The uplands immediately surrounding the cranberry bogs, often from 10 to 50 feet high, frequently well wooded, furnish ideal conditions for wind dispersion of first-stage gipsy moth larvæ, the principal means by which both wet and dry cranberry bogs become infested.

When trees are allowed to grow close to and overhang the bog, larvæ may drop or spin down from the branches and reach the cranberry vines. When heavy infestations obtain in the wooded borders and are not destroyed, defoliation is likely to occur, and the larvæ may crawl from the upland onto the bog in search of food and cause serious damage, as these large larvæ feed upon both new and old foliage, even eating the bark from the vines. These are the three principal ways (wind, dropping, and crawling) by which

[1] The writer wishes to express his appreciation to A. F. Burgess, Dr. J. N. Summers, and I. T. Guild for their helpful suggestions and advice, which have added materially to the accuracy and value of this paper, and to the last for the map and upland trench drawings; to F. H. Mosher for notes relative to the killing of the embryo in gipsy moth eggs by winter flooding of cranberry bogs; to W. N. Dovener for the enlarged drawing of the terminal bud of the cranberry plant; and to C. E. Hood for the preparation of the photographic illustrations—all of the Bureau of Entomology; to Dr. H. J. Franklin, superintendent of the cranberry substation of the Massachusetts State Experiment Station, Wareham, Mass., for valuable information relative to the growth of the cranberry plant and bog management; and to J. W. Smith, meteorologist in charge of the U. S. Weather Bureau at Boston, Mass., and his assistants for information relative to wind currents, temperature, and the setting up and management of the recording instruments.

cranberry bogs become infested with gipsy moth larvæ. In view of the fact that cranberry foliage is not a very favored food which gipsy moth larvæ seek by choice, and as the bog does not offer favorable conditions for reproduction of the moths from year to year, it is obvious that wind dispersion is an important, if not the most important, factor to be considered in studying the infestation of bogs.

WIND DISPERSION OF GIPSY MOTH LARVÆ.

HISTORY.

The first investigations of wind dispersion of the first-stage gipsy moth larvæ were made in 1910 by A. F. Burgess and recorded in Bulletin No. 119 of the Bureau of Entomology. These investigations established the fact that the young gipsy moth caterpillars, soon after they emerged from the egg, were carried considerable distances by the wind. This was the first indisputable explanation of the origin of isolated infestations in woodlands, as well as those that were frequently located in territory outside of the known infested area. The spread of this insect in a northeasterly direction year by year, it was found, was due to the fact that the wind usually blows from the southwest at the time when the young caterpillars first reach the tops of the trees.

In 1913–14 C. W. Collins carried on a series of experiments to determine the distance young caterpillars would be carried by the wind. The results of these experiments are recorded in Bulletin No. 273 of the U. S. Department of Agriculture, in which it is shown that under favorable conditions the small caterpillars were carried $13\frac{1}{2}$ miles. Later experiments have demonstrated that they may be carried 20 miles, and it is probable that under the most favorable conditions the spread is even greater.

SELECTION OF A BOG FOR EXPERIMENTAL PURPOSES.

Several bogs in the cranberry region were examined and the one that seemed best suited for the experiments was in the northern part of Carver, Plymouth County, Mass. This bog was approximately oval in form, about 3,600 feet long and 2,000 feet across at its widest part. The bordering uplands were typical of the region, consisting of elevations, from 10 to 50 feet in height, well wooded with pine, oak, birch, and some maple, with a few stands made up mainly of oak and birch. Egg clusters of the gipsy moth were found in these bordering woodlands, and were particularly plentiful on the western border. Some sections of this area were already in bog, one portion was in process of reconstruction, and the remainder was the bed of a pond that had recently been drained for the purpose of converting the whole area into one large cranberry bog. (Pl. I, Fig. 2.)

OBSERVATIONS ON WIND DISPERSION.

To determine the number of caterpillars blown upon this bog, traps were located at points shown on the map (Fig. 1) and continuous observations taken during the period in which the larvæ

FIG. 1.—Sketch map of Muddy Pond Bog, showing location of traps.

were carried by the wind. Record was made of temperature, with Draper self-recording thermometers, one at the bog level and another at the top of the observation tower described later; and wind

FIG. 1.—GIPSY MOTH LARVA DESTROYING ALL PROSPECTS OF A CRANBERRY CROP.

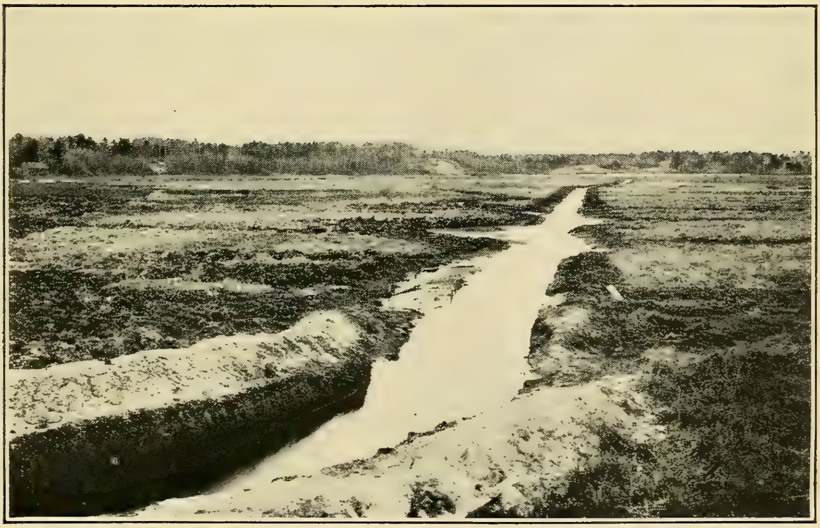

FIG. 2.—GENERAL VIEW OF MUDDY POND BOG, CARVER, PLYMOUTH COUNTY, MASS., LOOKING SOUTH FROM THE DIKE.

THE GIPSY MOTH ON CRANBERRY BOGS.

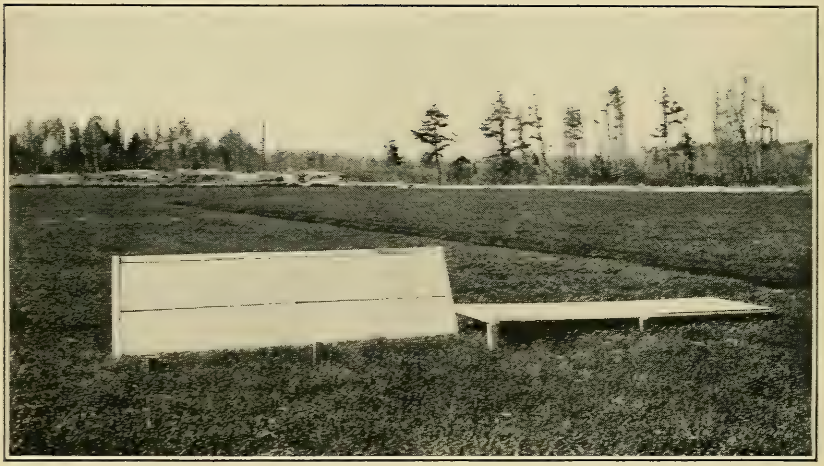

FIG. 1.—HORIZONTAL TRAP USED FOR CAPTURING WIND-BORNE GIPSY MOTH LARVÆ, SHOWING CONSTRUCTION.

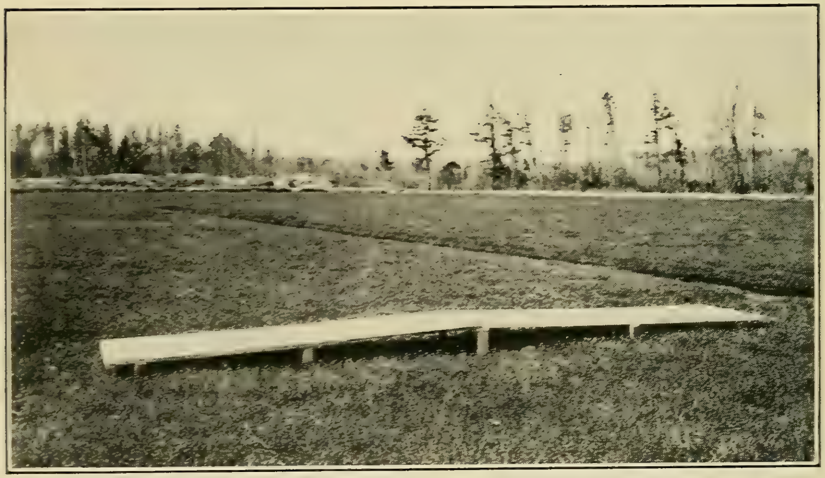

FIG. 2.—SAME TRAP SHOWN IN FIGURE 1 IN PLACE ON MUDDY POND BOG.

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velocity was recorded at a point about 25 feet above the bog level by a Robinson cup anemometer. The direction of the wind was also noted at hourly intervals during the day. The traps made it possible to count the caterpillars falling upon a known area, under given conditions, and at different locations on the bog, and to compare these records from year to year.

DESCRIPTION OF TRAPS.

The traps used by Burgess and Collins in previous wind dispersion experiments were constructed of 1-inch mesh wire poultry fencing, erected in a vertical position, and made in several sizes, their principal object being to demonstrate the certainty of wind dispersion.

A study of the results of these experiments indicates that quite a percentage of the caterpillars, particularly when the wind attained a velocity of 20 miles or more per hour, were blown through the meshes of the wire, notwithstanding the fact that the wire was well covered with commercial sticky tree-banding material. Eight horizontal traps having a solid surface were used in the bog experiments, numbered 1, 2, 3, 4, 7, 8, 9, and 12, and two vertical traps numbered 10 and 11. (Fig. 1.)

The horizontal traps were 20 feet long and 2 feet 8 inches wide, outside measurement. These dimensions were adopted for two principal reasons: First, to facilitate inspection of the surface, and, second, to reduce the danger of wind damage. For convenience in handling, they were made in two sections, each 10 feet long. The framework was made of wood 1 inch thick and 2 inches wide with a strip through the center to prevent the covering from sagging. (Pl. II, Fig. 1.)

Cotton cloth was first used for covering the frame, but this was not satisfactory, owing to its tendency to sag and hold rain water. Wall board was substituted, and proved very effective. Supporting stakes were driven into the bog at such height that when the frame was nailed to them, the two sections sloped from the center toward either end, in order to shed all moisture. (Pl. II, Fig. 2.)

The upper surface of the wall board was given a coat of outside white paint, which helped materially in distinguishing the small gipsy moth larvæ from the myriad of midges and other insects that are caught upon the trap. After the paint was dry the surface was marked off into 64 oblong sections 8 inches wide and 15 inches long. This made it possible to be sure that the whole surface was inspected and saved considerable time in making collections of larvæ that were caught on the trap.

Finally, the whole surface was covered with a coating of commercial sticky tree-banding material about one-fourth inch in thickness to serve as a trap for the caterpillars.

Later, improvements were made by setting the traps practically level, with an additional center support running longitudinally and serving as a ridge, which gave a slight pitch to either side, forming a perfect watershed. They were also raised to stand about 2 feet above the bog surface, particularly to facilitate inspection.

No. 10, the solid-surface vertical trap, was constructed of wall board, with the upper edge of the trap 9 feet above the surface of the bog. Twelve 8-inch holes were cut through the wall board and covered with $\frac{1}{4}$-inch mesh wire screen in order to reduce the force of the wind, but more particularly to prevent a cushion of air from forming in front of the trap. The whole surface, wall board and wire, was given a coating of commercial sticky tree-banding material as in the case of the horizontal traps. (Pl. III, Fig. 1.) Trap No. 11 was constructed in the same manner as No. 10, with the exception that three-fourths inch mesh wire netting was used for a surface. (Pl. III, Fig. 2.) All traps, with the exception of Nos. 10 and 11, were erected with the longer dimensions running east and west. Nos. 10 and 11 were erected vertically, facing east and west. In order to obtain information regarding the number of caterpillars and how far they were blown onto the bog, these traps were located at varying distances from the bog border.

RECORD OF TRAP OBSERVATIONS.

Trap observations have yielded information in regard to the number of caterpillars carried by the wind and as to the conditions under which they are carried.

The time of hatching the gipsy moth caterpillars is governed by the temperature. It is evident that in order to control infestations on bogs careful attention must be given to this factor. (See Table 1.)

TABLE 1.—*The variation of time in hatching and dispersion of gipsy moth caterpillars during the period covered by observations at Muddy Pond Bog, Carver, Mass.*

Year.	First hatching noted.	First larvæ taken on traps.	Time of maximum dispersion on traps.	Time between first hatching and maximum dispersion.	Time between first trap record and maximum dispersion.
				Days.	*Days.*
1916	May 9	May 22	May 25-26	16–17	3–4
1917	19	26	June 3, 4, 5	15–17	8–10
1918	7	10	May 15–16	8–9	5–6
1919	6	15	May 18, 19, 20	12–14	3–5

As a result of these observations it will be seen that the time of greatest dispersion follows from 13 to 14 days after hatching. It should be noted, however, that on uplands independent observations have shown that this period is shorter.

With the exception of the year 1917, the woodland surrounding Muddy Pond Bog was lightly infested with the gipsy moth. During that year there were a few scattered pockets on the western edge of the bog where a medium infestation existed. No heavy infestations were noted during the years that these experiments were conducted. The results of the observations for 1917 may therefore be taken as illustrating what might reasonably be expected in any similar infestation, and are given in detail in Table 2.

TABLE 2.—*Trap record for the season of 1917 giving the total number of gipsy moth larvæ taken from each trap and total for each day of dispersion, Muddy Pond Bog, Carver, Mass.*

Trap No.	May.		June.											Total.
	26	31	1	2	3	4	5	6	7	8	9	10	14	
1	0	4	3	4	24	8	8	3	0	0	0	0	0	54
2	4	(1)	12	12	(1)	43	(1)	35	(1)	3	0	4	(1)	113
3	3	(1)	10	11	(1)	38	8	8	(1)	2	(1)	(1)	(1)	80
4	(1)	(1)	(1)	22	(1)	11	(1)	10	(1)	1	(1)	(1)	(1)	44
7	16	11	26	28	169	135	46	10	10	4	2	7	1	465
8	11	15	17	12	86	149	54	11	4	5	2	7	0	373
9	5	4	9	3	58	47	20	3	2	1	2	3	2	159
Total	39	34	77	92	337	431	136	80	16	16	6	21	3	1,288

[1] No examinations made.

From Table 2 it will be noted that the largest numbers of larvæ were taken from the traps nearest the border of the bog, the number gradually diminishing as the distance from the border increased.

It is interesting to note the results secured on the two vertical traps. On No. 10, which was constructed of wall board, 255 larvæ were caught, while on No. 11, which was a wire trap, only 121 were secured. As these two traps were placed in equally favorable locations, it is evident that many larvæ passed through the wire screen. It is probable that wire treated with commercial sticky tree-banding material but having one-fourth-inch mesh would be much more effective. It is also interesting to note the difference between the number of larvæ taken on horizontal trap No. 9 and vertical trap No. 10. They had the same number of square feet of surface exposed, and although they were located near together, 159 were taken on the former and 255 on the latter. This shows conclusively that the number of wind-borne larvæ caught on a vertical surface is not a fair index of the number that will drop on a horizontal area of the same size. The density of infestation on low vegetation, when insects are

carried by the wind, should be determined by horizontal rather than vertical traps.

A total of 1,288 first-stage larvæ were taken on 385 square feet of horizontal trap surface, or an average of 3.3 larvæ per square foot.

Table 3 summarizes the information secured on the horizontal traps exposed on Muddy Pond Bog during the years 1916 to 1919. It will be noted that the number of larvæ caught in 1917 far exceeded the total for any other year. This was largely due to a slightly heavier infestation and more favorable weather for wind dispersion when the larvæ were in the first stage.

TABLE 3.—*Wind dispersion data for gipsy moth larvæ collated for the four-year (1916–19) period.*

Year.	Number of horizontal traps.	Trap surface.	Total number of larvæ trapped.	Number of larvæ taken per square foot of trap surface.	Days of dispersion.	Days of heaviest dispersion.	Larvæ taken on days of heaviest dispersion.	Percentage of total number trapped.
		Sq. ft.						
1916	4	240	111	0.4	15	2	72	64.8
1917	7	385	1,288	3.3	20	5	1,076	83.5
1918	9	500	132	.2	15	5	97	73.4
1919	1	55	197	3.9	13	5	172	87.3

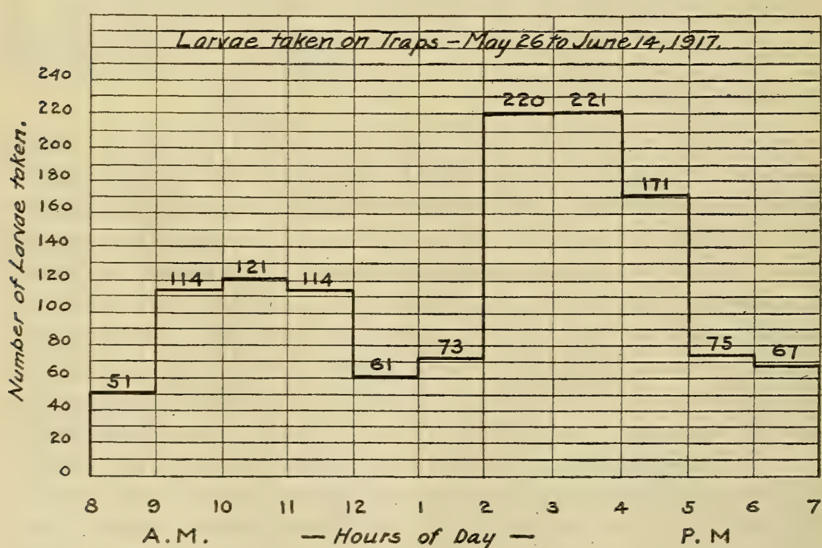

FIG. 2.—Showing two daily periods of maximum wind dispersion.

Figure 2 shows graphically the number of first-stage larvæ taken on the traps during the whole time of dispersion in 1917. This shows very clearly the important fact that there are two daily dispersion

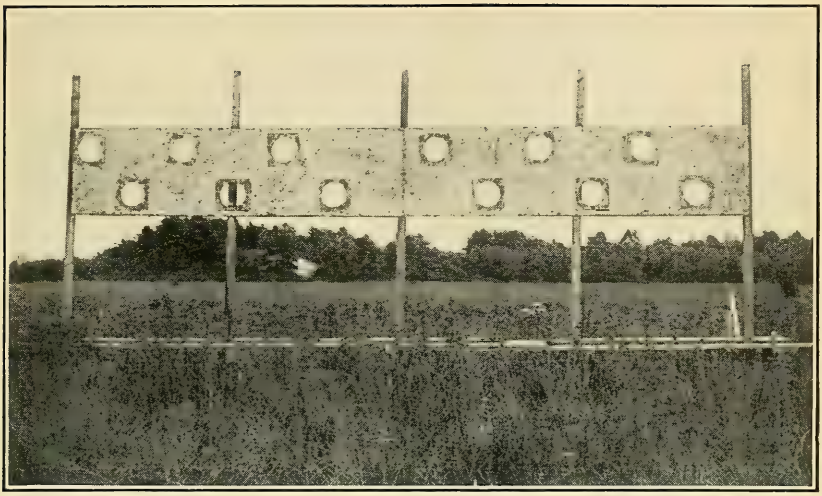

FIG. 1.—VERTICAL TRAP NO. 10, SHOWING CONSTRUCTION.

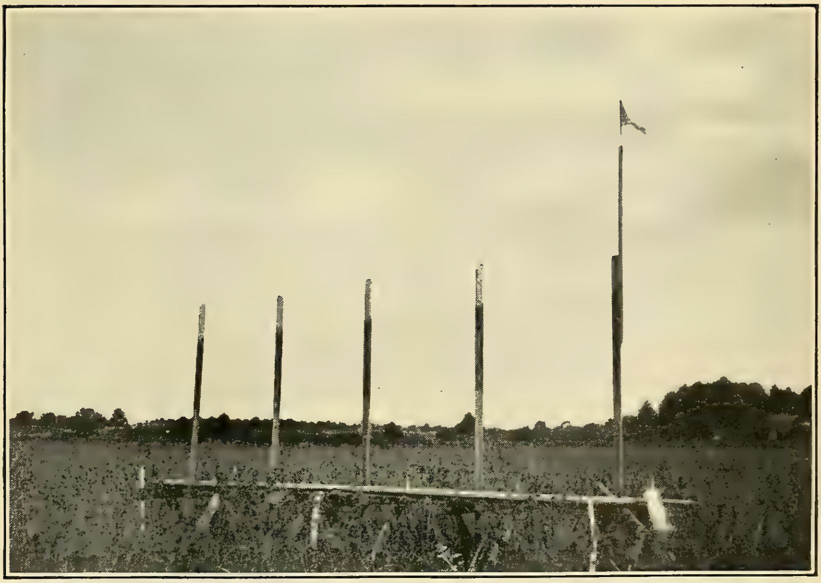

FIG. 2.—VERTICAL TRAP NO. 11, CONSTRUCTED OF WIRE POULTRY FENCING.

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TOWER SURROUNDING WHITE OAK TREE, FROM WHICH THE FEEDING HABITS OF FIRST-STAGE GIPSY MOTH LARVÆ WERE STUDIED.

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periods, viz, 9 a. m. to 12 m. and 2 to 5 p. m.;[2] and, furthermore, the observations of four consecutive years give substantially the same results. The small number of larvæ dispersed from 12 m. to 2 p. m. is not due to lack of favorable conditions either of temperature or wind velocity, for the mean temperature and wind velocity for that period of the day have both been found very favorable for heavy dispersion. The two periods of dispersion are due to a movement in search of food and are discussed more fully under the heading "Feeding habits on white-oak foliage" (p. 10).

The data from the traps secured from 1916 to 1919 prove that in order to have caterpillars dispersed in large numbers it is essential to have, first, a "medium" to "heavy" infestation; second, a temperature above 70° F.; third, a wind velocity of from 8 to 15 miles per hour. It has been found that a fairly steady wind blowing 10 to 12 miles per hour will disperse more larvæ, other conditions being favorable, than wind of higher velocity which blows intermittently.

FEEDING HABITS ON CRANBERRY FOLIAGE.

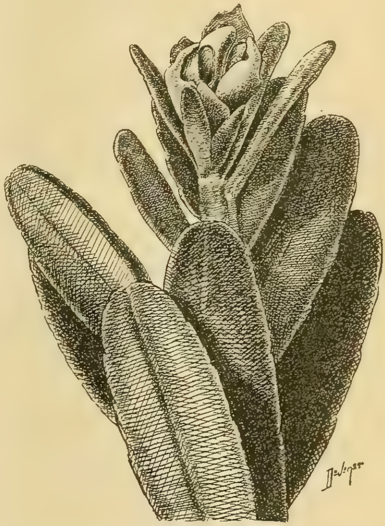

FIG. 3.—Terminal bud of cranberry plant showing injury caused by first-stage gipsy moth larvae.

Experiments have determined that under laboratory conditions gipsy moth larvæ can not be successfully carried through the several stages on cranberry foliage alone. This information was obtained in 1914 by F. H. Mosher and recorded in Bulletin No. 250 of the U. S. Department of Agriculture. In obtaining this information Mr. Mosher used feeding trays devised by W. F. Fiske, formerly of the Bureau of Entomology, with cranberry foliage inserted in crook-necked vials, filled with water, in order to keep the food fresh.

Bog observations have shown that the young first-stage larvæ begin their feeding on cranberry by attacking the contents of the terminal buds. They first eat through or between the bud scales, and then consume the tender undeveloped leaves within, leaving nothing but a shell formed by the bud scales. (Fig. 3.) By the time the caterpillars have reached the second stage the terminal buds not already

[2] All observations recorded in this bulletin were made according to Eastern standard time.

destroyed will have expanded into new shoots, and feeding is then confined almost entirely to the stems of these shoots, not to the leaves and buds. (Pl. I, Fig. 1.) In this way a large percentage of the new growth may be entirely destroyed, provided the infestation is sufficiently heavy. The same habit of feeding is continued through the later stages, until the supply of new growth is exhausted, then the older leaves may be attacked, and the vines stripped, provided, again, that the caterpillars are numerous enough to be forced to seek this less attractive food.

It is obvious that a few caterpillars can do a great amount of damage, first to the terminal bud from which is produced the season's fruit, and second by causing a branching growth of the plant. This damage to the terminal bud may occur before the owner realizes that his bog is infested.

FEEDING HABITS ON WHITE OAK FOLIAGE.

In the observations made in 1916–19 concerning the dispersion by wind of first-stage gipsy moth larvæ, it became evident, from the count of larvæ taken from the traps, that there are two periods of the day during which maximum dispersion occurs. From this fact it was inferred that there are, correspondingly, two daily periods of activity, as the larvæ would be more likely to be carried by the wind when crawling over leaf surfaces, limbs, or trunks of trees than when at rest. To verify this inference it was decided to make a study of the habits of first-stage larvæ as they are found in tree tops, where the earliest feeding usually appears, and where also the relation between the feeding habits and wind dispersion could be more satisfactorily studied.

A white oak about 30 feet high was selected near the border of Muddy Pond Bog. Around this tree was erected a tower 16 feet square at the base, 8 feet square at the top, and 25 feet high. A flooring was placed around the branches on top of this tower, thus bringing the upper 5 feet of the terminal branches in position for close examination and observation of the movements of young larvæ. (Pl. IV.)

On May 19, 1919, when observations were started, the leaves on this tree had begun to unfold, some of which would measure an inch in length, giving considerable protection to the young larvæ, as well as supplying food. It was found that the first feeding by first-stage gipsy moth larvæ after reaching the foliage was confined to the leaf hairs, principally on the underside of the leaves. After feeding in this manner for a day or two they began to feed on the tissue of the leaf, later eating through the tissue. The information relating to the feeding periods of first-stage gipsy moth larvæ, collated for the whole period of observation, furnishes what can be

considered as a continuous record from 3.45 a. m. until 7.30 p. m. These observations determined that feeding began soon after daylight, gradually increasing as the temperature increased, until it reached its maximum from 9 to 11 a. m. when it began to diminish, reaching a minimum during the midday, then gradually increasing again, reaching its maximum from 3 to 5 p. m., and gradually decreasing after this hour, a majority of the larvæ seeking shelter on the underside of the leaves by 7 p. m. Wind dispersion records cited show practically no movement of small caterpillars between 11 a. m. and 3 p. m., the period when there is practically no feeding and very little activity.

INJURY BY A GIVEN NUMBER OF LARVÆ.

When a new cranberry bog is planted the vines are usually set in rows 12 inches apart, and the same distance in the row. The increase of the vine area is by runners radiating out from each plant, in all directions, eventually forming a dense mass of vines over the whole bog surface. From these runners upright shoots grow, and under normal conditions increase in height by growth from a terminal bud, and it is upon this new growth that the fruit is borne each season. It is evident that any injury to the terminal buds reduces the amount of fruit in proportion to the number of buds destroyed. With the object in view of obtaining some definite information on this question an experiment was undertaken to determine the amount of damage to cranberry vines that would result from a heavy infestation of gipsy moths. Three pens were built 3 feet square, inside measurement, with sides 2½ feet high. On the outside of each pen, 6 inches from the top, four strips of board were attached at an angle of 30 degrees. Each pen was then forced into the bog about 6 inches and the sand firmly tamped both inside and outside of pens to prevent escape of larvæ. On the underside of this overhang and 6 inches from the top on the inside of each pen bands of commercial sticky tree-banding material were applied in order to prevent the escape of larvæ that were placed on the square yard of vines inclosed and to prevent other insects from gaining entrance to the pen. (Pl. V, Fig. 1.)

From year to year during the period covered by these studies varying numbers of first-stage larvæ have been placed in these pens each season and the injury to the vines, as well as the feeding habits of the larvæ on cranberry foliage, has been carefuly noted.

The results of these experiments have shown that an infestation of two larvæ to the square foot has destroyed nearly all the new growth of cranberry foliage. An infestation averaging one larva

to the square foot would materially reduce the crop and would necessitate flooding or spraying in order to prevent damage

Plate VI, Figure 1, shows a section of the surface of the vines in the above-mentioned pen and when compared with Plate VI, Figure 2, showing a similar area just outside of the pen, on the bog proper, with the vines in full bloom, the loss of the new growth is manifest.

MORTALITY OF FIRST-STAGE LARVÆ.

General observations on Muddy Pond Bog, particularly in connection with the pen experiments, have shown that there is a varying percentage of mortality among the several larval stages of the gipsy moth, after they reach the cranberry vines. This mortality is probably greatest in the first stage, owing to several factors. The principal factor is reduced vitality, since larvæ hatching from egg masses that were deposited upon conifers or other nonfavored food species had used up a considerable percentage of their vitality in searching for food before they were blown from the tree onto the vine surface. Their vitality was further reduced in crawling over the vines before approaching starvation finally forced them to feed upon the buds or new stalks of the cranberry vines. While in this weakened condition the larvæ are more susceptable to cold, particularly when accompanied by rain. That there is quite a difference between the temperature at the tops of trees and that at the bog surface was demonstrated by the use of recording thermometers. The platform at the top of the tower constructed around the white oak tree on which feeding observations were made was about 50 feet above the bog level. A comparison of the thermometer records made at the top of the tree and at the surface of the bog shows that the temperature averaged 5.2° F. cooler at the bog surface than at the top of the tree for the night period during the 6 days of heaviest wind dispersion, viz, May 25 to 30, inclusive. From 6 p. m. May 29 to 5 a. m. May 30 the average temperature was 11.3° F. lower at the bog surface than at the top of the tower. At 1 a. m. May 30 it was 15° F. lower at the surface of the bog than in the tree top, the maximum difference in the locations during the period. This was the coldest night of the period, and gave the greatest range of temperature. The above temperatures were obtained from the thermometers in latticed shelters.

There is also a high mortality among first-stage gipsy moth larvæ on cranberry bogs due to disease, predacious enemies, and other causes that are not well understood. All of these agencies, together with the rather unfavorable nature of the cranberry foliage as a food, combine to bring about an enormous reduction of the wind-blown larvæ.

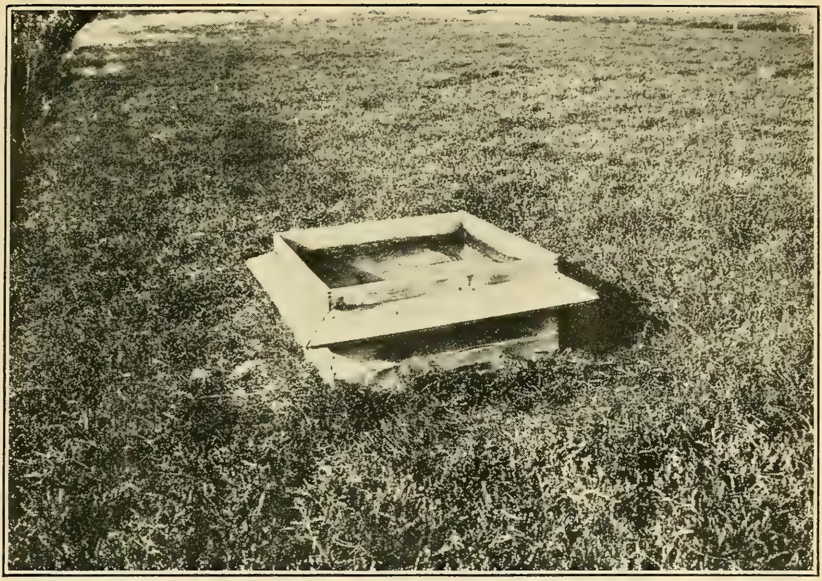

FIG. 1.—PEN USED TO CONFINE GIPSY MOTH LARVÆ WHILE STUDYING THE INJURY CAUSED BY THEIR FEEDING ON CRANBERRY PLANTS.

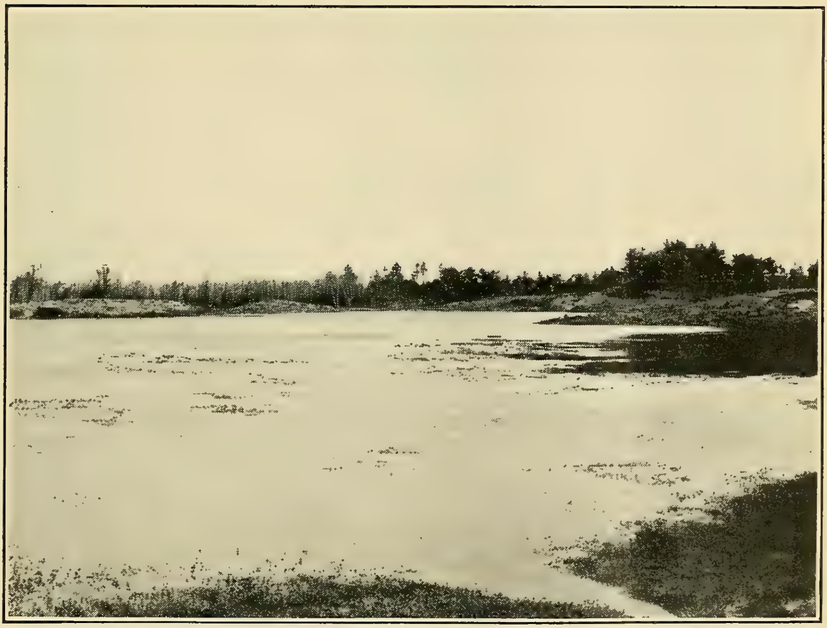

FIG. 2.—SHOWING AN UNEVENLY GRADED CRANBERRY BOG FLOWED TO DESTROY WIND-BORNE GIPSY MOTH LARVÆ. EXPOSED PORTIONS SHOULD BE SPRAYED TO INSURE COMPLETE PROTECTION.

THE GIPSY MOTH ON CRANBERRY BOGS.

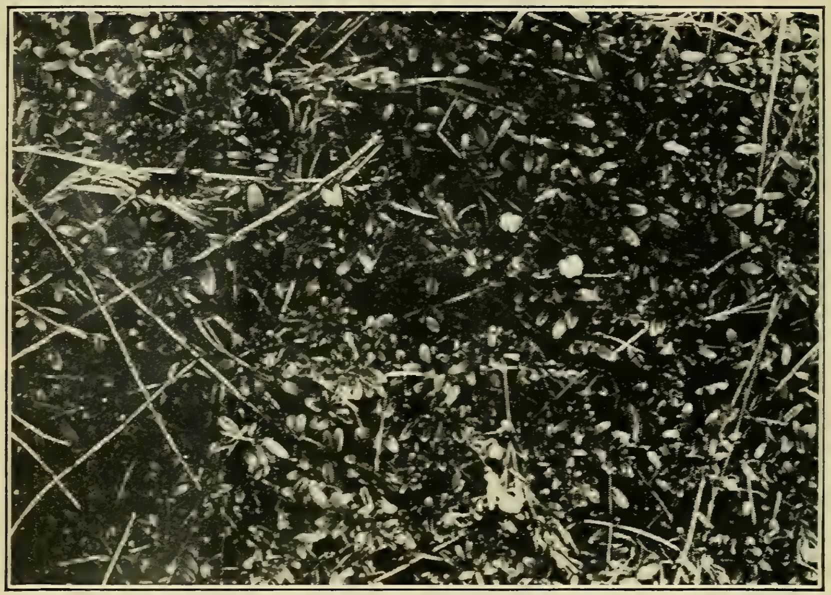

FIG. 1.—SECTION OF CRANBERRY FOLIAGE INSIDE OF PEN, SHOWING INJURY CAUSED BY 36 GIPSY MOTH LARVÆ. NOTE ABSENCE OF BLOOM. PHOTOGRAPHED JULY 12, 1917.

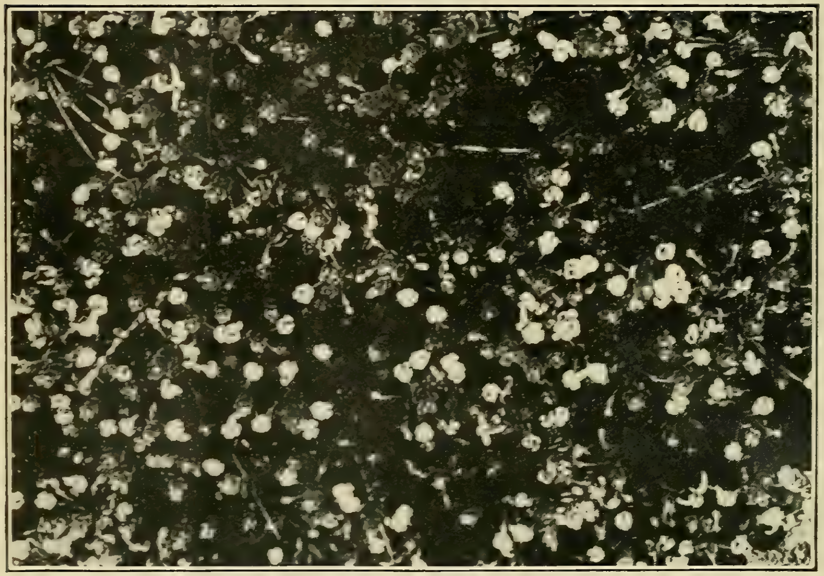

FIG. 2.—SECTION OUTSIDE OF PEN WHERE NO FEEDING BY GIPSY MOTH LARVÆ OCCURRED. PHOTOGRAPHED JULY 12, 1917.

THE GIPSY MOTH ON CRANBERRY BOGS.

RECOVERY OF CRANBERRY VINES FROM GIPSY MOTH FEEDING.

The soils of cranberry bogs are bound to vary in different bogs, owing to location, character of the peat constituents, and variation in grading. Often it is necessary to remove nearly all the peat in some sections of a bog in order to get the proper grade. When such conditions occur there is an uneven distribution of water; consequently the resulting crop will vary and the recovery of vines after injury will vary.

Muddy Pond Bog would be rated as a dry bog during the whole period that observations have been carried on. Whenever defoliation has occurred it has meant the loss of a crop for two years. After the buds or new growth were destroyed the vines would make a second growth from dormant buds, but would not form fruit buds. The second year, if no feeding occurred, the vines would make a normal growth and develop strong fruit buds, which would produce a heavy crop of berries the second year from defoliation, provided no climatic or insect injury prevented. Observations on wet bogs with a controllable water supply have shown that when the vines suffer the loss of the terminal fruit bud or of the later new growth, they usually make quick recovery, putting forth a strong second growth, and develop vigorous fruit buds. In a number of such instances a heavy crop of fruit has been produced the year following.

METHODS OF CONTROL.

The first requisite in the fight against a noxious insect is an accurate knowledge of its life history and all that pertains to its increase or decrease in the field. It is usually found that at some particular stage of its life it is more vulnerable than at any other. After this stage has been determined, the most effectual measure for control or extermination can be employed

Observations on the mortality of first-stage gipsy moth caterpillars have demonstrated the fact that soon after hatching from the protective egg mass they are very susceptible to injury by cold, and large numbers are destroyed at this time; particularly is this true should beating rains occur accompanied by low temperatures. *At this stage of their development they are most readily killed by a thorough application of an arsenical poison, and a comprehensive grasp of this fact is of vital importance to cranberry growers for efficient and economical control of this pest on cranberry bogs.*

HOW TO DETECT AN INFESTATION.

It is very difficult to detect first-stage gipsy-moth larvæ on cranberry foliage owing to their habit of dropping to the surface of the

bog when the vines are disturbed. One may obtain an approximate idea of the degree of infestation on his bog by either of the following methods, the accuracy of the estimate depending upon the care taken in performing the operation.

Pan Method.

Place a bright tin pan carefully among the vines, holding it with the right hand, inclined to the right at an angle of 45 degrees. With the left hand give the vines directly in front of the pan two or three quick slaps; then remove the pan and note the number of gipsy moth larvæ taken. Repeat this operation every 10 or 20 feet, until the whole bog is covered. By keeping a record of the number of larvæ taken and the number of times the pan was used, one may estimate the degree of infestation quite accurately.

Insect Net Method.

The degree of infestation on bogs may be determined also by the use of an insect net. Care should be taken to make even sweeps with the net, covering the same amount of vine surface with each sweep. By counting the number of larvæ taken after making a number of sweeps and estimating the area of vine surface covered by each sweep, one may estimate the infestation on the bog as a whole. The accuracy of this estimate will depend on the care taken in making the sweeps and the percentage of bog area covered. Whichever method is used, the line of collection should be from the shore line of the bog toward the center, as the infestation is usually heaviest nearer the shore.

CONTROL ON WET BOGS.

It has been demonstrated that no hatching occurs from gipsy moth egg masses placed among cranberry vines on bogs that are flowed from December 1 to May 1, while check experiments have shown normal hatching. It has also been found that egg masses placed under sand on dry bogs fall only 6 per cent below normal hatch.

These determinations were made during the winter of 1915 to 1916 and in 1917 by F. H. Mosher, who carried on experiments at North Saugus, Mass., and East Carver, Mass., to obtain information on this phase of gipsy moth investigations.

It is, therefore, evident that the methods of control adopted by the cranberry grower must be governed by the kind of bog infested, whether wet or dry. Owners of cranberry bogs located near an abundant supply of water, where flooding either by gravity or pumps can be quickly accomplished, have at hand the cheapest and most effective method for the control of this pest: First, by winter flowing, by means of which the partially developed larvæ in all eggs depos-

ited on the bogs during the previous season are destroyed; and, second, by holding the flowage until after the maximum time of wind dispersion has passed, which will result in drowning the young caterpillars that fall in the water. It is probable that the low temperature of the water is an important factor in the death of the caterpillars. It may be desirable to hold the winter flowage late, say from the 1st to the 15th of June, in order to control the blackhead cranberry worm (*Rhopobota naevana* Hbn.). When this is found desirable, it is evident that the gipsy moth infestation may be controlled at the same time. It is also probable that some of the other cranberry insects may be controlled in combination with efforts against the gipsy moth.

Observations have demonstrated that the maximum dispersion of first-stage larvæ of the gipsy moth occurs about 13 or 14 days after the first hatching is noted, but this period varies with the season; if there are 5 or 6 days when the temperature ranges from 75 to 85° F., or higher, rapid hatching will occur, and if it continues quite warm, the larvæ will reach the tops of trees sooner, resulting in an earlier dispersion. The best guide to determine when this may occur is the development of white oak leaves. When the leaf buds begin to unfold it is safe to assume that the temperature has been high enough to cause hatching of gipsy moth eggs.

Should the spring be late and the average temperature be low before hatching, and continue so after hatching, then the dispersion period will be correspondingly delayed, and extended over a longer period; in any case, however, there is a time of maximum dispersion, and this will occur, as stated, about 13 or 14 days after the first hatch. The closer the bog owner watches the upland conditions the better able he will be to control effectually an infestation on his bog.

In control by flooding, only complete submergence is effectual. If through lack of sufficient water, or irregularities in the surface of the bog, there are sections where a considerable number of vine terminals are out of water (as shown in the right center of Plate V, Figure 2, and to a less degree through the central section), even with a light to medium infestation on a bog these terminal shoots become actual life rafts for hundreds of larvæ that have crawled up the vines as the flooding gradually progressed, or reached them as the larvæ were blown over the surface of the water by the wind. When any considerable number of these terminal shoots project above the water it is imperative that the larvæ be brushed from the vines by using a common hand hayrake, drawing and pushing the vines under water several times with the back of the rake head. Unless this is done, there is likely to be considerable damage on these partially submerged sections of the bog. In the immediate foreground and

on the right of Plate V, Figure 2, there will be noted sections of the bog entirely out of the water. Flooding will not control an infestation in such cases. These must be controlled by spraying.

CONTROL ON DRY BOGS.

Gipsy moth infestations on dry bogs can be controlled only by intelligent application of some arsenical poison, either in the wet or dry form. It is probable that with more efficient apparatus for the application of dry poison, it will be the most economical and satisfactory way of applying poison to cranberry foliage. The leaf of the cranberry vine being glabrous, it is very difficult to get poison spray to adhere in sufficient quantities for satisfactory results unless the poison is applied in mist form. *Great care should be taken not to allow the mist to continue long enough in one section to reach beyond the dew point. If this should occur, the liquid will run off, leaving only a very thin deposit of the poison on the leaves, not enough to destroy the larvæ present.*

Observations have shown that in case of an infestation on a dry bog, resulting from egg masses deposited the previous season, it is imperative that the application of poison should be made soon after hatching is noted on the uplands, and also that it should be applied in a mist form in order that the largest amount of poison possible may settle on the terminal bud. It is important that the bud be covered thoroughly in order that the larvæ may get enough poison to cause death before they can eat so far into the buds as to cause injury. Six to eight pounds of arsenate of lead paste (or one-half of this amount of dry lead) to 100 gallons of water should effectually control gipsy moths in the first two larval stages if properly applied.

If during the first stage only light winds prevail, dispersion will be minimized, and the central areas of medium or large sized bogs may not become infested to such a degree that spraying will be necessary over the whole area. Careful tests should be made by the pan or net method to determine the degree of infestation along the bog border nearest the infestation on the upland, should there be any, and spraying operations governed accordingly. This applies to wet bogs in case it is not desirable to control an infestation by flooding.

Should a bog be infested with the later larval stages of the gipsy moth, from whatever cause, the only recourse is to spray with a strong solution of arsenate of lead—using from 12 to 15 pounds of lead paste to 100 gallons of water, and using the same care in application as advised for the first larval stage.

CONTROL ON UPLANDS.

After the gipsy moths have reached the second stage, and all danger of wind dispersion is reduced to a minimum, heavy infestations may occur on the uplands in the vicinity of cranberry bogs, and if heavy enough to cause defoliation the caterpillars, in their march for a supply of food, may move in the direction of a bog, and owing to the large amount of food necessary to maintain the hordes of larvæ, may become a serious menace to the bog itself.

There are several methods of control that may be used to advantage in such an emergency, and one or more of those mentioned below should be adopted in order to protect the bog.

The woodland border of the bog may be cut back for the space of 100 feet or more, and possibly the section of woodland from the edge of this cutting to the infested area may be sprayed. If, however, this distance should happen to be only a few hundred feet, the spraying would not accomplish the desired result, because only a few of the thousands of larvæ present would consume enough of the poisoned foliage to cause death. The others would march on in search of more food.

When such conditions occur, an open ditch on the upland, back from the bog border, may be dug, 12 to 15 inches deep and 18 inches wide, the earth being thrown toward the oncoming horde of larvæ, and the side of the ditch nearer the bog being made perpendicular. At the top of this perpendicular side a board about 1 foot wide should be placed at an angle of 45 degrees, overhanging the ditch, supported by stakes driven into the soil; earth should be banked on the outside of this board in such a way as to close up all spaces at the base of the board caused by the irregularities of the surface of the ground. The undersurface of the board and supports should be well smeared with a commercial sticky tree-banding material before being placed in position. The larvæ upon reaching this band will fall into the ditch, and should be sprinkled with crude oil from an ordinary watering pot. In case of extremely heavy infestations it may be necessary to clean out the mass of dead larvæ before the last hordes reach the ditch. (Fig. 4.)

If a protective belt is already cut around the bog it is highly desirable that all sprout growth be kept down by bruising the sprouts from the stumps for two or three years, using a dull ax with which to perform this operation, mowing all other small growth close to the ground, and burning all the débris. This well-cleaned border may help greatly in controlling some of the other insects that breed on the upland border, thereby reducing their ravages on the bog itself.

When light infestations are present and the immediate upland border is clear of overhanging brush, border ditches may offer all necessary protection, provided they are in proper condition. To be effectual they should not be less than 15 inches wide and from 15 to 20 inches deep with the bog side of the ditch perpendicular and as smooth as possible, in order to give little foothold to the crawling larvæ. If not detrimental to the vines or crop, a few inches of water should be maintained in the ditch with a little crude oil on the surface. The larvæ dropping from the land side into the ditch will become smeared with oil and suffocate. Should some larvæ reach the bog side and attempt to crawl up the smooth surface, being weakened by partial suffocation they will drop back into the oil bath.

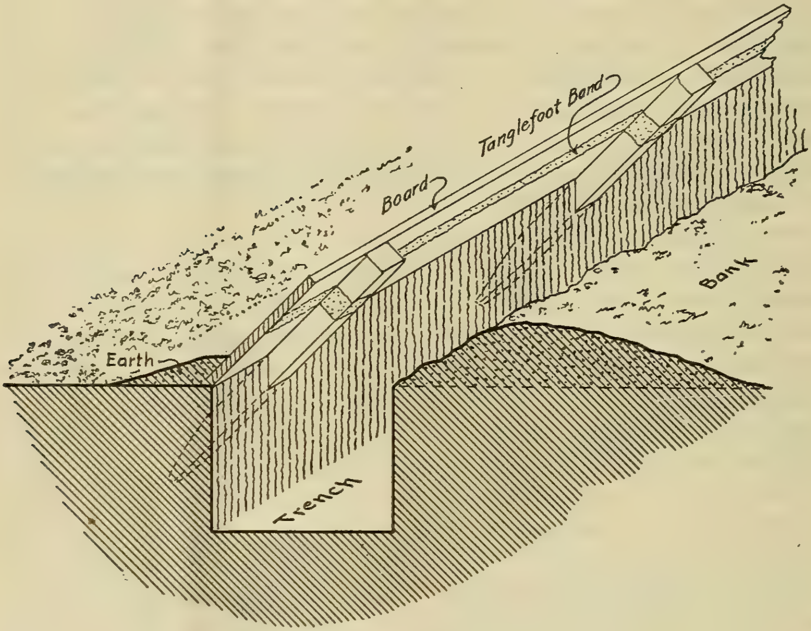

FIG. 4.—Cross section of an upland trench, with board in position.

Should the infestation prove too heavy to be controlled by the oil and water a board about 1 foot wide may be set against the smooth surface of the bog side of the ditch, resting on stakes driven in the bog at an angle of 45 degrees, care being taken to make tight joints. The underside of the board and stakes should be smeared with a good coat of commercial sticky tree-banding material. It is obvious that with an infestation heavy enough to require the use of the board, the ditch might have to be frequently cleared of the dead bodies of the larvæ in order to remain effective.

The method to be used for the control of an upland infestation must be decided by the owner of each bog. He must be governed by the condition and particular surroundings of the bog in question. Any of the foregoing methods should give satisfactory results if attended to properly.

SUMMARY.

Infestations of gipsy moths upon cranberry bogs are due principally to wind dispersion of first-stage larvæ, which occurs only when conditions of wind velocity and temperature are favorable. The time when maximum dispersion prevails is usually not longer than from two to five days. Because of the activity of the young caterpillars in seeking food there are two daily periods of maximum dispersion, between 9 a. m. and 12 m. and between 2 and 5 p. m.

Mortality of first-stage larvæ is very great, large numbers perishing from low temperatures, unfavorable food, predacious insects, and disease. The embryos in all gipsy moth eggs deposited on cranberry bogs are killed by winter flowage, when the bogs are flowed from December 1 to May 1.

Upon deciduous foliage in general the feeding of the first-stage larvæ is upon the leaf hairs, but the injury to cranberry plants is caused by feeding upon the terminal buds, and later upon the new growth. As a rule vines recover more quickly from injury upon wet bogs than upon dry ones.

Flooding is the most effective method of control upon wet bogs; but spraying is the only method which can be employed on dry bogs. *In order to obtain the most satisfactory results, spraying should be done before wind dispersion begins.*

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METHODS OF WINTER-WHEAT PRODUCTION AT THE FORT HAYS BRANCH STATION.

By John S. Cole, *Agriculturist*, and A. L. Hallsted, *Assistant in Dry-Land Agriculture, Office of Dry-Land Agriculture Investigations, Bureau of Plant Industry.*

CONTENTS.

WINTER WHEAT IN ELLIS AND ADJOINING COUNTIES IN KANSAS.

The Fort Hays branch experiment station is located in Ellis County. This county is in the western tier of the solid block of 28 counties which with 2 others were designated in the 1901 report of the Kansas State Board of Agriculture [1] as "million-bushel" counties in wheat production.

The statistics gathered by the State Board of Agriculture and published in its biennial reports make it possible to follow the history of each crop from the beginning of agriculture in the county and the region and to determine the rotation and cultural problems as they present themselves in the accomplished fact of actual practice.

Ellis County is recorded as containing 900 square miles, or 576,000 acres. Since the first attempt was made at cultivation in 1870 the area under the plow has increased until in 1920 the total area for all crops reached 270,867 acres. But with the extension of the cultivated acreage the rate of increase is diminishing. A distinct break in the curve showing the total acres of all crops in the county is noted in 1903. For the 15 years preceding that date the increase

[1] Kansas. State Board of Agriculture. Biennial Report, v. [3–27], 1874–1919–20. Topeka, 1874–1921.

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apparent drops in some of the recent years have been due to winter losses rather than to a restriction of the acreage attempted. It has been shown that winter wheat in Ellis and Rush Counties occupies about 72 of every 100 acres in crop. For Russell County the proportion is 63 and for Rooks and Trego about 50.

These statistics show that in such counties as Ellis and Rush if every acre in other crops were seeded to winter wheat only about one-third the total wheat acreage would be provided for. After this is done 2 of every 3 acres of wheat must still be sown directly following wheat. As every acre in other crops is not seeded to wheat it seems safe to conclude that in the area represented by the Fort Hays (Ellis County) branch station approximately two-thirds of the wheat is grown following winter wheat.

The greatest single problem, measured in terms of acres involved, that the agricultural practice of the section presents is how to prepare wheat stubble for seeding winter wheat.

The relative importance of other crops in the rotation possibilities offered by their acreage is shown in Table 2. This table shows the average number of acres occupied by winter wheat and the other more important crops during each decade or partial decade of the period from 1874 to 1920, inclusive. It is shown by this table that corn comprises the largest acreage of any of the other crops and that the grain and forage sorghums make up the second largest acreage, with a comparatively small acreage devoted to small grains, millet and other crops.

TABLE 2.—*Average numoer of acres in Ellis County occupied by winter wheat and the other more important crops during each decade or partial decade of the 47-year period from 1874 to 1920, inclusive.*

Decade.	Areas cropped (acres).											
	Winter wheat.	Rye.	Spring wheat.	Corn.	Barley.	Oats.	Potatoes.	Sorghum.	Millet.	Milo.	Kafir.	Alfalfa.
1874 to 1880	5,827	206	239	3,825	60	494	139	69	1,536	......	......	......
1881 to 1890	26,129	4,013	740	7,934	373	2,794	435	3,053	3,972	......	......	......
1891 to 1900	110,458	2,438	156	13,366	4,467	3,491	557	6,110	3,672	28	2,194	201
1901 to 1910	177,686	524	175	21,553	3,272	2,349	630	5,883	3,340	47	6,806	1,677
1911 to 1920	163,584	403	8	33,065	7,873	6,072	651	12,155	1,592	1,799	15,448	2,248

The effect that this heavy cropping to wheat may be having upon yields is an important question worthy of the most careful study. A period of 47 years would seem to be sufficiently long to afford conclusive evidence on the single concrete question of whether yields are increasing, unchanging, or decreasing; but on examination it is found to be relatively short when considered in connection with the great fluctuations in yields from year to year and for irregularly recurring periods of years.

The average yields of winter wheat per acre each year in each of the five counties, Ellis, Russell, Rush, Rooks, and Trego, are presented in Table 3. In the last column of the table the average yield of the five counties for each year is given.

TABLE 3.—*Average yields of winter wheat in Ellis, Russell, Rush, Rooks, and Trego Counties, Kans., for each year for the 47-year period from 1874 to 1920, inclusive.*

Year.	Yields per acre (bushels).						Year.	Yields per acre (bushels).					
	Ellis.	Russell.	Rush.	Rooks.	Trego.	Average.		Ellis.	Russell.	Rush.	Rooks.	Trego.	Average.
1874	20					20.0	1899	8	9	6	9	6	7.6
1875	16	18	15			16.3	1900	17	21	16	16	14	16.8
1876	12	12	11			11.7	1901	11	16	9	13	11	12.0
1877	20	20	19	19		19.5	1902	4	3	4	9	8	5.6
1878	22	23	23	22		22.5	1903	17	18	18	20	18	18.2
1879	7	10	3	11		7.8	1904	9	13	8	9	5	8.8
1880	3	6	6	6	3	4.8	1905	5	10	7	14	9	9.0
1881	11	12		10	11	11.0	1906	5	14	6	10	6	8.2
1882	21	20	16	23	19	19.8	1907	9	11	7	12	5	8.8
1883	13	11	9	15	8	11.2	1908	14	14	12	13	6	11.8
1884	27	29	26	29	23	26.8	1909	6	11	8	13	10	9.6
1885	7	8	10	8	7	8.0	1910	13	16	15	12	6	12.2
1886	16	14	14	14	12	14.0	1911	2	4	6	4	3	3.8
1887	15	7	8	10	8	9.6	1912	12	15	10	16	8	12.2
1888	13	15	10	17	13	13.4	1913	6	6	3	7	2	4.8
1889	26	24	24	20	10	20.8	1914	19	19	22	21	19	20.0
1890	9	9	9	9	5	8.2	1915	11	13	10	14	10	11.6
1891	12	16	7	20	16	14.2	1916	13	13	13	15	22	15.2
1892	20	21	18	22	17	19.6	1917	2	5	4	3	3	3.4
1893	.27	.05	.16	.6	0	.2	1918	9	10	6	7	6	7.6
1894	2	1.65	.48	2.7	3	2.0	1919	9	11	9	11	9	9.8
1895	4	3	4	1.5	6	3.7	1920	18	17	16	25	20	19.2
1896	5	7	4	7	6	5.8							
1897	15	12	12	12	14	13.0	Average	11.6	12.7	10.5	12.8	9.7	11.
1898	12	16	8	10	9	11.0							

If these yields are studied as a whole by determining each year the average of all yields available at that time, a generally falling average yield is shown. The decrease, however, is becoming very small in recent years. Such a study alone would lead to the conclusion that yields are decreasing. But a further study shows that this apparent continuing decrease is due entirely to the persistent effect on the average of the high yields obtained in the early years. The high yields in the early years are shown most effectively in Table 4. In this table the yields given in Table 3 are averaged by decades and partial decades. In this table, as in these statistics in general, the evidence of each county is confirmed by that of the others.

The average of the five counties shows for the 7-year period from 1874 to 1880 an average yield of 14.1 bushels, for the decade 1881 to 1890 an average of 14.4 bushels, for the decade 1891 to 1900 an average of 9.6 bushels, for the decade 1901 to 1910 an average of 10.4 bushels, and for the decade 1911 to 1920 an average of 10.8 bushels.

This shows a higher average in the seventies and eighties than has been attained since and indicates a maintenance of yields during the three later periods. This phase of the question will be studied more in detail than simply by the decade averages.

TABLE 4.—*Average yields of winter wheat in Ellis, Russell, Rush, Rooks, and Trego Counties, Kans., for each decade or partial decade of the 47-year period from 1874 to 1920, inclusive.*

Decade.	Average yields per acre (bushels).					
	Ellis.	Russell.	Rush.	Rooks.	Trego.	Average.
1874 to 1880	14.3	14.8	12.8	14.5	....	14.1
1881 to 1890	15.8	14.9	14.0	15.5	11.6	14.4
1891 to 1900	9.5	10.7	7.6	10.1	10.1	9.6
1901 to 1910	9.3	12.6	9.4	12.5	8.4	10.4
1911 to 1920	10.1	11.3	9.9	12.3	10.2	10.8

In considering acreage it was noted that the year 1891 marked the time when stability was reached in the proportion of wheat to all crops. If the previous period be eliminated and the study of yields is begun with that year, the curve is very different from the one obtained when it is included. In the nineties yields were high, low, and again high. The 10-year average of Ellis County for 1891 to 1900, inclusive, was 9.5 bushels per acre. The succeeding averages obtained by including the data of each succeeding year in a new average until a 30-year average is obtained in 1920, do not depart from this by more than 0.5 bushel in either direction. The 24-year and 25-year averages were exactly the same as the 10-year average; the 29-year average was 0.1 bushel lower, and the 30-year average 0.1 bushel higher. The average of the five counties parallels that of Ellis very closely.

It is impossible to recognize any progressive change in yields during this period of 30 years.

In the early years a lesser area of land was under cultivation, as well as a smaller proportion of it in wheat. The smaller acreage perhaps contributed to more timely work. Undoubtedly the best land as a rule was brought under cultivation first. During the development period a considerable proportion of the wheat would be seeded on newly broken prairie sod or on land only a few years from sod. Such land is free from the weeds and diseases that follow a crop after its introduction into a new country.

With the passage from first development to a stabilized condition on old soil there was a marked drop in yields. The term old soil is intended to express only a relative condition as distinguished from new land which still enjoys the physical effect of the prairie sod and its relative freedom from the weeds and diseases that accompany cropping. The evidence of a number of dry-land experimental farms seems to show this change occurring in from four to seven years on individual fields and farms.

Since the drop that marked the passage to a stabilized condition there has been no measurable change in yields. If the system in itself has resulted in any decrease of yields, such decrease has been

overcome by other factors tending to improvement, such as better varieties, treatment of seed, and the attainment of a higher average degree of efficiency of methods and machinery. There has been an almost perfect balance between the factors of decrease and increase. With an agriculture established for 30 years by devoting nearly 75 per cent of the cultivated acreage to winter wheat an unchanged average of yields has been maintained.

COOPERATIVE EXPERIMENTS IN METHODS OF WHEAT PRODUCTION AT THE FORT HAYS BRANCH STATION.[3]

The Fort Hays branch station of the Kansas Agricultural Experiment Station is one of the points at which the Office of Dry-Land Agriculture Investigations of the United States Department of Agriculture first arranged for cooperative work in the investigation of methods of crop production. Field experiments in crop rotation and cultural methods were started under this cooperation in 1906. The work at that time was started on 100 plats. None of these have been dropped nor their continuous history interrupted, but their number has been increased from time to time until 326 plats were occupied in 1920. Of this number 136 were in winter wheat.

Other crops, presented in the order of the number of plats occupied by each, are kafir, corn, oats, barley, spring wheat, milo, alfalfa, brome-grass, sorghum, field peas, and winter rye. The two last mentioned are plowed under for green manure.

In the first part of this bulletin figures were presented showing the acreage devoted to each crop by the farmers of the region. The averages of the annual yields obtained on the experiment-station plats tend in the main to justify, with one exception, the relative importance assigned to the several crops by the farmers. According to the station figures, corn occupies a higher place in the acreage of the region than it is entitled to by its yield.

The average yields in bushels per acre for the 15 years since the experiments were started in 1906 are as follows: Winter wheat, 16.1; spring wheat, 5.1; oats, 18.5; barley, 15.8; corn, 5.4; kafir, 14.9; and milo, 15.7.

The problem of wheat production in this section has been presented concretely and with it the obvious question of what is the experiment-station evidence on the possibility of increasing the average yield and increasing it profitably.

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[3] The Office of Dry-Land Agriculture Investigations was organized in 1906 with E. C. Chilcott as Agriculturist in Charge, who planned, outlined, and instituted these investigations and who still has general supervision of them. This bulletin has been prepared under his direction.

L. E. Hazen had immediate charge of the cooperative work in 1906, 1907, and 1908. Since 1909 it has been under the immediate charge of the junior writer.

The work is closely coordinated with that at 23 other stations on the Great Plains, and the conclusions are therefore presented with a greater degree of confidence than they would be were they based entirely upon the results of the single station.

The most valuable evidence perhaps is that from the oldest block of plats, which have a continuous record from 1906 to 1920, inclusive. There are 14 plats of winter wheat in this block. Four of these are cropped continuously to winter wheat by different methods, one is on fallow in a 2-year rotation (or alternation of wheat and fallow), seven are in 4-year rotations, and two are in 6-year rotations containing brome-grass or alfalfa.

The land had been under cultivation for some years before the experimental work was started. The experiments being started in the spring of 1906, spring wheat was sown that year. Results with winter wheat are available for the 14 years from 1907 to 1920, inclusive. The yields from the 14 plats and also the average yield of the county for each year of this period are given in Table 5. The 14-year averages are shown at the bottom of the table.

TABLE 5.—*Yields of winter wheat in Ellis County, Kans., and in 14 plats at the Fort Hays branch station for the 14-year period from 1907 to 1920, inclusive.*

Year.	Ellis County.	Yields per acre for the several plats and rotations (bushels).													
		Continuous wheat.				C–D, fallow, wheat.	57, corn, barley, fallow, wheat.	51, corn, barley, rye,[a] wheat.	92, corn, barley, peas,[a] wheat.	55, kafir, barley, rye,[a] wheat.	56, kafir, barley, peas, wheat.	53, rye,[a] barley, corn, wheat.	54, peas,[a] barley, corn, wheat.	141, brome-grass (3 yrs.), oats, corn, wheat.	142, alfalfa (3 yrs.), oats, corn, wheat.
		A, late-fall plowing.	B, early-fall plowing.	E, subsoil.	F, list.										
1907	9	11.7	18.2	13.6	12.4	11.2	12.3	9.3	14.0	12.3	14.5	7.0	9.9	7.8	8.8
1908	14	25.6	23.3	30.5	28.1	32.3	29.2	21.8	(b)	23.2	9.4	11.7	11.9	11.3	9.4
1909 [c]	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1910	13	20.5	27.8	39.8	36.8	42.5	42.7	22.5	40.1	30.9	39.3	35.0	29.5	23.3	25.1
1911	2	0	.3	.3	.6	2.6	5.2	1.2	1.6	2.3	2.3	.5	.6	0	0
1912	12	2.3	13.8	20.1	26.6	29.2	27.7	0	4.9	13.2	10.1	8.6	13.9	19.0	12.9
1913	6	.8	2.3	4.1	8.4	10.3	16.4	8.7	6.8	8.1	4.6	2.5	8.1	11.6	6.5
1914	19	20.6	24.8	25.3	23.1	21.6	19.9	19.8	18.5	23.5	22.5	21.4	24.0	19.9	6.7
1915	11	9.3	13.1	14.9	13.9	11.3	17.5	19.8	21.3	21.8	20.4	18.8	20.7	21.0	19.7
1916	13	8.7	22.7	27.6	23.1	33.8	31.8	28.8	29.8	33.8	33.2	31.5	36.6	34.8	23.5
1917	2	0	2.0	2.6	0	7.1	3.3	5.3	1.5	3.8	1.7	.3	.3	0	0
1918	9	9.7	14.9	14.4	24.8	35.8	12.6	4.7	13.7	12.0	13.7	10.7	9.3	9.4	9.3
1919	9	17.9	16.8	18.9	19.8	10.0	13.5	14.6	11.0	13.7	12.7	20.6	24.7	21.8	20.3
1920	18	19.9	24.4	26.0	24.2	37.0	33.3	30.9	31.1	32.6	32.2	27.8	37.7	30.0	29.1
Avge.	10.2	10.5	14.6	17.0	17.3	20.3	19.0	13.4	14.9	16.5	15.5	14.0	16.2	15.0	12.2

[a] Plowed under for green manure. [b] Spring wheat by error. [c] All wheat on the plats destroyed by hail.

CONTINUOUS AND ALTERNATE CROPPING TO WHEAT FOR 14 YEARS.[4]

Of these 14 plats the greatest interest attaches to the four that are continuously cropped to wheat and the two on which wheat and fallow alternate. These have no rotation number but are designated as A, B, E, and F, continuously cropped, and C and D, on which wheat and fallow alternate. Plats C and D are located between plats B and E in the field. Plat A is late plowed and harrowed twice immedi-

[4] Since this manuscript was prepared the 1921 results have become available. They effect only minor changes in the averages and do not change the conclusions derived from them. The season was relatively unfavorable to wheat raised continuously without plowing, to late-fall plowing, and to wheat following corn and kafir. In the methods-of-fallow experiment the yield of the late-plowed plat in the pair N–O was relatively low and that of the listed plat in the pair P–Q was relatively high.

ately after plowing. It receives no other cultivation or treatment. Plat B is plowed as early as practicable after harvest, disked or harrowed immediately after plowing, and given such subsequent cultivation until seeding as may be necessary to prevent the growth of weeds and vegetation. This usually requires three or four cultivations with harrow, disk, or shovel cultivator. Plat E is given the same treatment as B except that it is subsoiled at the time of plowing. Plat A is plowed about 5 inches deep, B from 6 to 7 inches, and E plowed to the same depth as B and subsoiled an additional 7 to 9 inches. Subsoiling, however, is not done every year. It was done preceding the crops of 1907, 1908, 1911, 1914, 1917, 1919, and 1920. Plat F is furrowed with a lister at the time of plowing B and E. Furrows are run at distances of 3½ feet, the same as if planting corn, and to a depth of about 6 inches. Thereafter until seeding, the plat is given the cultivation necessary to prevent weed growth and to level the surface by seeding time. This usually requires one cultivation and two harrowings or two cultivations and one harrowing.

The average date of winter-wheat harvest on these plats has been July 1 and the average date of seeding September 29. A period of 90 days thus elapses between harvest and seeding. The average date of plowing plat A has been September 12, or 73 days after harvest and 17 days before seeding. Plat B has been plowed on the average date of August 2, 32 days after harvest and 58 days before seeding. Plat A thus lies in stubble for 41 days, practically six weeks longer than B; or, stated in another way, B is in a state of bare cultivation before seeding for six weeks longer than A. This period of six weeks in August and early September is a summer period when vegetative growth is very strong provided there is any moisture to support it. For the 14 years under consideration the August precipitation has averaged 3.13 inches. During the same period July has averaged 2.67 inches and September 1.96 inches.

It may seem that an interval of 32 days between harvest and plowing is unduly long and that any advantage from early plowing might be further enhanced by shortening it. But this is the period fixed by experience as the shortest practicable when the crop is harvested with the binder and thrashed from the shock. The weather causes delays, particularly in clearing the crop from the ground either by stacking or thrashing. Plowing, listing, or disking consumes considerable time, so it is improbable that for any considerable acreage the interval could be shortened in practice. Farms are not likely to be so equipped as to permit the simultaneous conduct of plowing and harvest operations. When the crop is harvested with a header, as much of it is in this section, cultivation may be started somewhat sooner than is possible where the grain is bound.

As exhibited in Table 5, the lowest yield has been from plat A. This has yielded not only the lowest of any of the plats continuously cropped to wheat but the lowest of any plat in the field. The seed bed is quite commonly described as loose and lumpy; germination and stand may be poor; winter survival is sometimes poor; growth is not as vigorous as on other plats; and it is one of the first to suffer from drought. Only twice in 14 years has its yield exceeded that of plat B. Its 14-year average yield of 10.5 bushels per acre is practically the same as the Ellis County average of 10.2 bushels for the same period. In exactly half the years its average has exceeded that of the county and in the other half it has been lower. As might be expected, the county average is smoother than that from a single plat or field because it neither descends to the complete failure nor rises to the height of high yields that the latter may experience.

Plat B, which is plowed one month after harvest, six weeks earlier than A and two months before seeding, has exceeded A in yield every year except 1908 and 1919. While A has a 14-year average of only 10.5 bushels per acre, the average yield of B for the same period is 14.6 bushels. This is an increase of 4.1 bushels per acre on account of the earlier plowing and subsequent cultivation. This stores water in the soil which protects to some extent against drought and prepares a generally moist and solid seed bed in which germination, fall growth, and winter survival are better than on the late plowing.

The yield from this method exceeds the county average by 4.4 bushels per acre. As it is a very practicable method of preparing wheat stubble for wheat it appears from the comparative results of these two plats alone that the county average should be susceptible of increase.

Plat E is a duplicate of B in time of plowing and in cultivation after plowing. As has been explained it is in addition subsoiled from time to time. Its yield averages 17 bushels per acre, or 2.4 bushels more than B. In following the yield of B it confirms the advantage of early plowing. It also appears to show some advantage from subsoiling. This increase from subsoiling is more marked at Fort Hays than at other dry-land stations and more marked with winter wheat than with other crops. The subject has been treated exhaustively in another publication.[5] Subsoiling would necessarily delay plowing, and so on a large acreage any increase from it might be neutralized by the poorer returns shown to follow late plowing.

Plats E and F lie side by side. As already described, plat F is listed instead of being plowed. Its yield follows that of E very closely, sometimes one and sometimes the other having the heavier yield. Its 14-year average is 17.3 bushels per acre. This is 0.3 bushel more

[5] Chilcott, E. C., and Cole, John S. Subsoiling, deep tilling, and soil dynamiting in the Great Plains. *In* Jour. Agr. Research, v. 14, no. 11, p. 481–521, 4 fig. 1918. Literature cited, p. 521.

than E, 2.7 bushels more than B, and 7.1 bushels more than A. Contrary to the objection of delay and increased cost raised against E, this method is quicker and cheaper even than B. With a given force the land can be listed more rapidly than it can be plowed, and consequently the benefits of early cultivation may be more fully realized with this method than with plowing. Except in 1917, when both this and the late-plowed plat A were reduced to total failure, it has generally stood drought better and longer than B. Plats E and F have generally been about the same in this respect, better than the continuously cropped plowed plats but not as good as the plat on fallow.

The other method in this series of plats that grow wheat alone is alternate wheat and fallow on plats C and D. In the even years C is cropped and D fallowed and in the odd years D is cropped and C fallowed. By using twice the area of land a crop is thus produced each year on fallow for comparison with those obtained by continuous cropping. The 14-year average yield from this method is 20.3 bushels. This is practically double the county average, only a fraction of a bushel less than double the average from late plowing, less than 50 per cent increase over early plowing, and only 3 bushels per acre more than early listing. The yield of fallow from this method and of fallow and of green manure throughout this bulletin is the yield from the area actually in crop. In computing the economic value of these methods consideration must be given to the fact that an equal area in preparation for a crop is producing nothing.

It not infrequently happens that the greater water supply and other more favorable conditions of this method promote a growth so heavy that it suffers from lodging and fungous diseases. When conditions do not continue so favorable the heavier vegetative growth of this method may demand more water than is available from both that stored in the soil and supplied by rain and the damage to it from drought be relatively and actually greater than to plats having less growth because they started under less favorable conditions.

The evidence of the plats indicates that on land cropped to wheat alone the fallow can not be profitably employed on such acreage as it is possible to cultivate early, but that land that can not be prepared early might better be fallowed than seeded on a late-plowed poor seed bed. The principle of the fallow (cultivation to form a firm, moist seed bed and the storage of water before seeding) is correct, but the greater part of its benefits may be realized by cultivation in the period of three months between harvest and seeding. These are conclusions based on the averages of 14 years. They may not hold true in any one individual year. A heavy rainfall in the fallow period and a drought or deficiency of rainfall in the growing period favors the fallow. Drought during the fallow period decreases the

initial advantage of the fallow, and heavy rainfall in the growing period may put it at an actual disadvantage.

The relation of the moisture in the soil at seeding time to the yield of winter wheat has been discussed in detail in a previous publication,[6] which presents the data of both yield and soil moisture from these plats for the years 1907 to 1913, inclusive.

The evidence of these plats discloses nothing new. The value in this section of early preparation of wheat stubble when it is to be resown to wheat has been demonstrated often and is well known. But the length of the record and the relation of the yields to the average yield of the county makes an impressive object lesson. The low average for the county indicates that by far too large a proportion of the acreage is late and poorly prepared. The average is of course lowered by many other things besides failure to prepare the land early, but the importance of timely work and its necessity on a larger proportion of the acreage if the general average is to be increased can not be over emphasized.

Bulletin 178 of the Nebraska Agricultural Experiment Station[7] reporting results from the North Platte substation shows a much smaller increase from early-fall plowing than has been obtained at the Fort Hays branch station.

A simultaneously prepared manuscript on winter wheat in western Nebraska by L. L. Zook, published as Bulletin 179 of the Nebraska Agricultural Experiment Station, reports results with winter wheat following winter wheat, corn, fallow, and green manure at the North Platte (Nebr.), Scottsbluff (Nebr.), Akron (Colo.), and Ardmore (S. Dak.) stations. While all of these stations show relatively small increases from early preparation where the crop follows winter wheat or other small grain, they also show marked increases in yield where it follows corn, green manure, or fallow. The relations between yields from continuous cropping to winter wheat and from other methods at these stations are similar to those obtaining between late plowing of continuously cropped ground and other methods at the Fort Hays branch station.

These stations are farther north, at higher altitudes, and have less precipitation than Fort Hays. Harvest is later and frost and seeding are earlier. The growing period after harvest being shorter and drier than at Fort Hays, there is less opportunity for conducting an effective fallow between harvest and seeding. On the other hand, the lower precipitation at these stations contributes to a greater response from the full fallow period.

[6] Call, L. E., and Hallsted, A. L. The relation of moisture to yield of winter wheat in western Kansas. Kans. Agr. Exp. Sta. Bul. 206, 34 p., 12 pl. (in text). 1915.

[7] Zook ,L. L. Winter wheat seed-bed preparation. Nebr. Agr. Exp. Sta. Bul. 178, 16 p., 2 figs. 1921.

WHEAT IN ROTATIONS FOR 14 YEARS.

Of the nine plats of wheat grown in rotations in this block, two follow immediately after peas as green manure, two follow rye as green manure, four are on disked corn ground, and one on fallow.

The highest average yield has been from the one on fallow in rotation No. 57. This is a 4-year rotation of fallow, winter wheat, corn on spring-plowed wheat stubble, and barley on disked corn ground. The wheat has averaged 19 bushels per acre. This should be compared with the yield of 20.3 bushels on fallow in the alternately cropped plats C and D that have been considered. The two have followed each other very closely in yield except in 1918, when the alternately cropped plat was very high and rotation No. 57 very low. For the other 13 years there is an average difference of only 0.3 bushel in favor of rotation No. 57.

No one of the other eight plats in rotations has averaged as much as either plats E or F continuously cropped to wheat.

Rotation No. 51 is the same as No. 57, except that in place of the bare fallow a crop of winter rye is turned under as green manure. This is plowed under on the average date of May 31. Thereafter until seeding, the ground is given the necessary cultivation, like the fallow, to keep it free from vegetation. Its average yield is only 13.4 bushels per acre.

Rotation No. 55 is the same as No. 51 except that it contains kafir instead of corn. It is rye for green manure, wheat, kafir, and barley. Its average yield of wheat is 16.5 bushels. It appears that the greater part, if not all, of the difference in the yield of wheat in this rotation and in rotation No. 51 is due to plat variation and experimental error rather than to the fact that one has kafir and the other corn two years before the wheat. Nearly 1 bushel of the difference is accounted for by the failure of the wheat in rotation No. 51 in 1912. This was caused by fall and winter soil blowing and was unquestionably due to location in the field. The average of the two plats following rye for green manure, one in rotation No. 51 and one in rotation No. 55, is 15 bushels per acre. This is only 0.4 of a bushel more than wheat on early plowing, less than wheat on subsoiled or early-listed ground, and 4.7 bushels less than the average of the two plats on fallow.

Rotation No. 92 is similar to No. 51, and rotation No. 56 is similar to No. 55, the difference being the replacement of the rye by a legume for green manure. Rotation No. 92 is peas for green manure, winter wheat, corn, and barley, and rotation No. 56 is peas for green manure, winter wheat, kafir, and barley. In the first four years, from 1906 to 1909, inclusive, cowpeas were used, but beginning with 1910 a change was made to field peas. Cowpeas grow in late season and are

not ready to plow under until in September. The average date for plowing under field peas has been June 20. This is three weeks later than the plowing under of rye, but the fallow period is more comparable than it could be with cowpeas. Rye, being ready to plow under three weeks earlier than peas, has a fallow period that much longer, and there is that element of difference in addition to the difference in the character of the crop. It is a difference, however, that is inherent in the nature of the crops and can not well be avoided. The average yield of wheat in rotation No. 92 is 14.9 bushels and in rotation No. 56, 15.5 bushels. Again, in this pair the higher yield is from the rotation having kafir instead of corn two years before the wheat. The difference, however, is too small to be significant. Rotation No. 92 has no record for 1908, as winter wheat was omitted from it by error. It was seeded to spring wheat, but the yield can not be used in comparisons with winter wheat. The average yield of the two plats following peas used as green manure is 15.2 bushels per acre. This is 0.2 bushel more than the average of the two plats following rye used as green manure. Each of the plats on peas has yielded more than one of the plats on rye, but less than the other.

The evidence presented by the wheat crop alone is not sufficient to distinguish any difference between a legume and a cereal as green manure. Any minor difference there may be is of little significance in comparison with the fact that neither one has produced yields as high as the less expensive bare fallow and only barely or not quite equal to those obtained from the best methods of preparation following a wheat crop. With the longer fallow period enjoyed by the green-manure plats it seems that their yield should exceed that following a wheat crop and more nearly approach that of the still longer period of the bare fallow. This is their general behavior at most dry-land stations.

Two other 4-year rotations contain green manure. Rotations No. 53 and No. 54 are similar to No. 51 and No. 92, with the positions of the corn and green manures exchanged. In these two the barley is on green manure and the wheat on disked corn ground. Rotation No. 53 is rye for green manure, barley, corn, and winter wheat, and rotation No. 54 is peas for green manure, barley, corn, and winter wheat. The average yield of wheat in rotation No. 53 is 14 bushels and in No. 54, 16.2 bushels per acre. This apparently shows a clear advantage of the legume over the cereal as a green manure that was not shown in the rotations where wheat immediately followed the green manure. The wheat in one of these rotations yields less and in the other more than wheat following wheat on early-fall plowing, but less in each than wheat following wheat on subsoiling or early listing. They of course yield markedly heavier than wheat following wheat on late-fall plowing.

While this discussion is confined to winter wheat, the data would be incomplete if the yields of the other crops in the rotations were omitted entirely. For convenience of reference, the average yields of the several crops in these rotations are shown in Table 6.

TABLE 6.—*Average yields of corn, kafir, barley,[a] and winter wheat in 4-year rotations at the Fort Hays branch station for the 14-year period from 1907 to 1920, inclusive.*

Item.	Yields per acre for the several rotations (bushels).						
	51, corn, barley, rye,[b] wheat.	92, corn, barley, peas,[b] wheat.	55, kafir, barley, rye,[b] wheat.	56, kafir, barley, peas,[b] wheat.	57, corn, barley, fallow, wheat.	53, rye,[b] barley, corn, wheat.	54, peas,[b] barley, corn, wheat.
Corn:							
Grain............bushels..	5.5	7.5	....	....	6.6	4.9	5.4
Stover............pounds..	2,514	2,410	....	....	2,361	2,315	2,417
Kafir:							
Grain............bushels..	....	....	18.3	20.3	....	....	....
Stover............pounds..	....	....	4,648	4,698	....	....	....
Barley..............bushels..	16.1	19.4	17.5	19.2	19.6	21.6	20.4
Wheat..................do....	13.4	14.9	16.5	15.5	19.0	14.0	16.2

[a] Barley is for the 13-year period from 1908 to 1920, inclusive. [b] Plowed under for green manure.

Corn following winter wheat the second year after rye used as green manure in rotation No. 51 has a 14-year average yield of 5.5 bushels of grain and 2,514 pounds of stover per acre. Corn on similar preparation after peas used as green manure in rotation No. 92 has averaged 7.5 bushels of grain and 2,410 pounds of stover per acre. In the similar rotation containing fallow instead of green manure, No. 57, corn has averaged 6.6 bushels of grain and 2,361 pounds of stover. Barley following the corn in these same rotations has averaged for the 13 years from 1908 to 1920, inclusive, 16.1 bushels in rotation No. 51, 19.4 bushels in rotation No. 92, and 19.6 bushels in rotation No. 57. It has been shown that the yield of wheat immediately following the green manure or fallow was 13.4 bushels after rye in rotation No. 51, 14.9 bushels after peas in rotation No. 92, and 19 bushels after fallow in rotation No. 57. When all three crops are considered the rye for green manure in rotation No. 51 shows to distinct disadvantage in comparison with peas or fallow. Between the other two rotations no choice is to be made from the behavior of the corn and barley, but for winter wheat the fallow rotation shows a distinct advantage over the one containing peas.

Rotation No. 53, rye for green manure, barley, corn, and winter wheat, has made average yields of corn, 4.9 bushels; barley, 21.6 bushels; and wheat, 14 bushels per acre. Rotation No. 54 is the same, with peas instead of rye for green manure. The average yields from it are corn, 5.4 bushels; barley, 20.4 bushels; and wheat, 16.2 bushels. Comparing the two rotations the higher yields of wheat and corn have been from the pea rotation and the higher yield of

barley from the rye rotation. It is doubtful whether the differences are significant.

The corn in these five rotations has made only three good crops. Some of the losses have been from grasshoppers and chinch bugs. These concentrate on the plats from the grain fields by which they are surrounded and sometimes cause losses which large fields would not suffer. To that extent the average may not be equal to the average that corn may attain in the section. But some of the losses have been from drought and hot winds, which are no more serious on plats than on larger fields.

The two rotations containing kafir have made average yields of 18.3 bushels of kafir grain and 4,648 pounds of stover in rotation No. 55, containing rye for green manure; and 20.3 bushels of grain and 4,698 pounds of stover in rotation No. 56, containing peas for green manure. Barley following the kafir has averaged 17.5 bushels in rotation No. 55 and 19.2 bushels in rotation No. 56. These yields of barley following kafir compare favorably with those following corn and are very nearly equal to the yields of barley following immediately after green manure. Barley in alternation with fallow on plats not previously introduced into this discussion has averaged 23 bushels per acre for the same period of years. The wheat in the rye rotation has averaged 16.5 bushels and in the pea rotation 15.5 bushels. These rotations clearly show the superiority of kafir over corn in the production of both grain and stover. The other crops in the rotations show no disadvantage from the kafir in them. Unfortunately there is not in this block any winter wheat immediately following kafir. The extent of work that could be started originally was limited, and the general experience and belief that wheat did not follow the sorghum crops successfully was accepted as sufficient reason for not including this method.

Two other rotations in this block introduce sod crops. Rotation No. 141 is oats on brome-grass sod, corn on spring-plowed oat stubble, winter wheat on disked corn ground, and three years of brome-grass. For several years the grass seed was sown in the winter wheat in the spring, but a stand was never obtained in this way. After failure to obtain a stand by this method the wheat stubble was plowed in the fall and the brome-grass seeded in the spring. Better results attended this method, but it is not always possible to get a stand and bring it through the summer. The rotation has been a failure as far as the grass crop is concerned. The only hay harvested was in 1916, 1919, and 1920. About half the time there has been a fair sod to break for oats. Breaking has been done in summer at the time of fall plowing. Oats have averaged 20 bushels per acre in this rotation, which is about the same as the average following grain crops, but in the years when a heavy sod has been broken the yield has been low.

Corn has averaged 6.3 bushels per acre, and wheat 15 bushels. This is about the average for corn and the same for wheat as the average of wheat on disked corn ground in the green-manure rotations.

Rotation No. 142 is the same as rotation No. 141, with alfalfa in place of brome-grass. The alfalfa is sown without a nurse crop in the first of the three years of alfalfa. Previous to 1913 not much success attended efforts to obtain a stand of alfalfa. Since that time there has always been a sod to break up, and generally there has been some hay production. The yield of oats has averaged 17.9 bushels per acre, which is less than in rotation No. 141 or from most methods by which oats have been raised. Corn has averaged 5 bushels per acre, which is next to the lowest yield of corn in this group. The average yield of wheat is 12.2 bushels, which is the lowest of any method except that of late plowing of wheat stubble.

These plats show clearly that the introduction of sod crops into the rotation will not increase yields, but has, on the contrary, the opposite effect to a degree largely dependent upon the success of the sod crop itself.

Diligent study has been made of the data from this block of plats to determine whether the averages for the entire period of experimentation afforded a correct basis from which to draw conclusions of the relative merits of the different methods and systems of cropping or whether some were having a cumulative effect in increasing or decreasing yields. The yield curves have been smoothed in various ways and the yields have been averaged for different periods and groups of years. Such studies have failed to reveal any changing relations in the yields of the different methods and rotations.

The evidence from the rotations in this block does not indicate that the farmers are wrong in devoting the large proportion that they do of the cropped acreage to winter wheat. Neither does it indicate that wheat grown following other crops yields more per acre than wheat following wheat, provided the stubble is plowed or otherwise cultivated soon after harvest so as to get the benefit of a fallow during the summer season between harvest and seeding.

METHODS OF FALLOW.

In presenting and considering in the foregoing pages the results on fallow, the method of fallow was not described. The method employed on those plats was what may be designated as the most intensive. Cultivation begins with early plowing after harvest. The ground is packed or worked down immediately after plowing and given during the summer and fall the cultivation necessary to prevent the growth of vegetation. The cultivation is in fact the same as early plowing to be sown to wheat. In the spring cultivation is continued. The ground is replowed in June and cultivation continued through

the summer until seeding time. The replowing is necessary to destroy the scattered deep-rooted weeds that may escape the surface-cultivating implements and to correct a fineness and compactness of surface that results from continued surface cultivation. Under this system a bare cultivated surface is maintained for about 14 months preceding seeding.

In 1913 an experiment was started to determine to what extent this fallow period might be shortened and the expense of the fallow reduced without reducing yields, or, more correctly speaking, to determine the effect on yields of reducing the length of the bare-cultivated period and the amount of work expended on the fallow. Four pairs of plats were set aside to be alternately cropped and fallowed. On the pair H–I the method above described was employed. These plats, therefore, duplicate the pair C–D from which results have been given. On the pair J–K the cultivated period is reduced by delaying the first plowing, which is the first cultivation, until late fall. This goes through the winter rough, as left by the plow, unless cultivation is necessary in winter to prevent blowing. The summer cultivation and replowing are the same as in the pair H–I. The plat to be fallowed in the pair L–M goes through the summer, fall, and winter in stubble. Its first cultivation is plowing in spring before vegetation makes very heavy growth. This usually has been in the last half of April. In 1915 this was replowed July 24; in 1916, August 1; and in 1918, June 13. By error it was plowed in the fall of 1913. In the summer of 1914 it was replowed August 20. In the pair N–O the bare-cultivation period is still further shortened by delaying the first cultivation until in June, when it is plowed. The actual dates of plowing have ranged from June 7 to June 24.

The yields from plats fallowed by these methods and others to be outlined are given in Table 7. The 7-year averages for the period 1914 to 1920 are 21.1 bushels from H–I, 21.6 bushels from J–K, 21.8 bushels from L–M, and 23.6 bushels from N–O. The first three methods run very close together, not only in the average but in each of the years. The last method was inferior in the drought of 1917 and decidedly superior in 1919. In 1919 those methods that had the rankest early growth and at one time the highest potential yield later suffered from lodging, storm damage, and fungous diseases and finally produced the lightest yield. This tendency, however, is not an unusual one at the Fort Hays branch station, and the performance record of methods that avoid it should not be discounted.

One year later, the experiment in methods of fallow was extended to include two more methods. The fallow plat in the pair P–Q is listed instead of plowed in the fall. The time of listing agrees in general with the time of plowing in the pair J–K. During the spring it is cultivated level, and it is plowed in June at the same time

the other fallow plats are plowed or replowed. Its treatment for the remainder of the season is the same as that of the others. The same method is followed in the pair R–S except that some time after listing in the fall a subsoiler is run in the lister furrows. Unfortunately it was necessary to locate this pair of plats in a block in another part of the field. The yielding power of the land is about the same, but results can not be compared too closely. The yields of these plats are also given in Table 7. For the 6-year period from 1915 to 1920, inclusive, the yield of P–Q has averaged 19.8 bushels and of R–S 22.2 bushels. In the same years H–I has averaged 20.1 bushels, J–K 21.0 bushels, L–M 21.3 bushels, and N–O 22.9 bushels.

The results of the whole experiment in methods of fallow show clearly that the essential period of the fallow is the summer months immediately preceding seeding. This conclusion was indicated in the continuous-cropping series by the close approach of the yields on early plowing to those on fallow. They also show, in connection with other experiments, that the essential part of the fallow is the maintenance of a bare surface (prevention of the growth of vegetation) during the active growing season and that the cultural methods by which this is accomplished are of minor importance from the standpoint of resultant yield.

TABLE 7.—*Yields of wheat from different methods of fallow at the Fort Hays branch station for the 7-year period from 1914 to 1920, inclusive.*

Year.	Yields per acre by the several methods (bushels).						
	Plats H–I. Early-fall plowed.	Plats J–K. Late-fall plowed.	Plats L–M. April plowed.	Plats N–O. June plowed.	Plats P–Q. Fall listed.	Plats R–S. Fall listed and subsoiled.	Rotation 570. Fallow 3 years.
1914	26.8	25.6	25.4	27.3	....	....	....
1915	17.3	20.4	16.8	16.3	19.3	17.8	18.8
1916	33.6	37.3	38.2	41.2	37.2	38.0	33.1
1917	6.8	6.3	7.5	1.0	8.1	11.8	10.4
1918	15.3	14.1	14.5	18.3	11.8	17.2	28.8
1919	9.0	9.8	10.2	22.4	13.7	13.3	9.0
1920	38.8	37.8	40.3	38.4	28.9	35.0	33.8
Average, 1914 to 1920	21.1	21.6	21.8	23.6	....	....	....
Average, 1915 to 1920	20.1	21.0	21.3	22.9	19.8	22.2	22.3

An experiment started in 1913 to provide material for the study of certain water relations of the soil is interesting in its evidence on the effect of the length of fallow. On the four plats known as rotation No. 570 the land is fallowed for three years and then cropped to winter wheat. These plats adjoin the pair R–S in the field. The yields from 1915 to 1920 are given in Table 7. The average yield for this period is 22.3 bushels per acre, which is less than the highest yielding plats with a single year of fallow. The only year when it

showed a marked superiority over the other methods was 1918. The result of this test tends to confirm the evidence that the full effect of the fallow in the region under consideration is realized by cultivation in the one summer prior to seeding.

WHEAT IN INTERTILLED STRIPS.

One of a group of experiments started in 1913 is a trial of wheat in intertilled strips. The single plat known as rotation No. 592 raises wheat continuously on early plowing. The wheat on this plat is sown with the ordinary drill set at the usual rate, but with a part of the feed cups closed so as to sow strips about 30 inches wide alternating with unseeded strips of the same width. The exact width has varied, depending upon whether a 6-inch, 7-inch, or 8-inch drill was used. As this and other experiments grouped with it were started in the spring of 1913, spring wheat was sown that year. In 1914 the methods under trial were in full operation and results are at hand for the 7-year period from 1914 to 1920, inclusive. The yields of this and other rotations or methods are given in Table 8.

TABLE 8.—*Yields of wheat by six different methods at the Fort Hays branch station for the 7-year period from 1914 to 1920, inclusive.*

Year.	Yields per acre by the several methods (bushels).					
	Rotation 592. Intertilled strips on fall plowing each year.	Rotation 591. Sown in stubble each year.	Rotation 401. Fallow, wheat, wheat, kafir.		Rotation 402. Fallow, wheat, kafir, kafir.	Plats N-O. In alternation with fallow.
			On fallow.	On fall-plowed wheat stubble.		
1914	18.3	21.3	22.2	20.7	15.6	27.3
1915	16.3	27.3	18.4	24.9	20.6	16.3
1916	25.1	23.7	38.1	41.3	27.6	41.2
1917	0	.3	7.9	1.1	8.8	1.0
1918	13.0	19.5	9.8	10.6	7.9	18.3
1919	18.3	23.7	15.3	24.6	16.3	22.4
1920	15.3	26.9	33.0	26.3	26.7	38.4
Average	15.2	20.4	20.7	21.4	17.6	23.6

GROWING WINTER WHEAT WITHOUT PLOWING.

The average yield of the intertilled wheat, designated rotation 592 has been 15.2 bushels. This yield may be fairly compared with 21.4 bushels on fall-plowed wheat stubble seeded solid in rotation No. 401, given in Table 8.

This method has sometimes been noted as standing drought better than solid seeding, but the limited number of plants have not been able to produce the yield of which the soil and water supply are capable.

The single plat known as rotation No. 591 grows wheat continuously without plowing. This plat was last plowed in 1912. It was double-disked, harrowed, and Acme harrowed in the fall of 1913,

and double-disked before seeding in 1916, 1918, and 1919. It has received no other cultivation or treatment except seeding and harvesting. Its average yield for the 7-year period from 1914 to 1920, inclusive, as shown in Table 8, is 20.4 bushels per acre. This may be properly compared with the yield of 21.4 bushels on early fall-plowed wheat stubble in rotation No. 401.

Further evidence on this subject is furnished by an experiment as to the frequency of plowing for winter wheat, which was started in 1916. This occupies six plats continuously cropped to winter wheat. Plat A is plowed each year, B is plowed one year and sown in stubble the next, C is plowed one year and sown in stubble two years, D is plowed one year and sown in stubble three years, E is to be sown in stubble continuously, and F, originally planned for another method, has been plowed each year except for the crop of 1917. The tillage on these plats is early plowing, which is worked down immediately and given necessary cultivation until seeding time. The plats sown without plowing receive no other treatment than a double-disking. In preparation for the crop of 1917 this was done at the time of early plowing. Since then it has been done at the time of late plowing. The yields from these plats for the 5-year period from 1916 to 1920, inclusive, are given in Table 9. The land was fallowed in 1915 and seeded that fall as a solid field. The plats were blocked out from the field in the spring of 1916. Differences in yield that year are natural differences between plats of uniform treatment. For 1917 plat A was plowed and the others seeded in disked stubble. All except plat A were consequently of uniform treatment. For 1918 plats A, B, and F were plowed, and C, D, and E were again seeded on disked stubble and again given uniform treatment. For 1919 plats A, C, and F were plowed, and for the fourth year D and E were seeded on disked stubble continued uniform. For 1920 plats A, B, D, and F were plowed, and uniformity between any of the plats disappeared.

In Table 9 the yields on plowed ground in the 4-year period from 1917 to 1920, inclusive, are printed in boldface type. Despite the plat variation, as shown by differences in yield when the treatment was uniform, the results are clear as to differences between plowing and not plowing in the years during which the experiment had been conducted, but they do not yet illuminate the question of how often plowing must be resorted to or how long it may be dispensed with. The average of each plat for the 4-year period from 1917 to 1920, inclusive, is given at the bottom of Table 9. In the present stage of the experiment perhaps a better comparison is afforded by determining the average yield each year of the plowed plats and of those not plowed. Such averages are shown in the right-hand columns of the table. In 1917 the one plowed plat was a total failure, due to a

thin stand and winterkilling, and five sown in disked stubble averaged 3.9 bushels per acre. In 1918 three plowed plats averaged 15.8 bushels and three not plowed 24.7 bushels. In 1919 three plowed plats averaged 19 bushels and three unplowed 22.2 bushels. In 1920 four plowed plats averaged 22.6 bushels and two unplowed 25.8 bushels. In four years the total gain from not plowing was 19.2 bushels, an average gain of 4.8 bushels per year. In this group of plats, as in rotation No. 591, which has not been plowed since 1912, there is no evidence of deterioration from the continued omission of plowing.

TABLE 9.—*Yields of wheat on plats continuously cropped to wheat but plowed at different intervals at the Fort Hays branch station for the 5-year period from 1916 to 1920, inclusive.*

[Yields following plowing shown by boldface type.]

Year.	Yields per acre (bushels).								
	Plat A.	Plat B.	Plat C.	Plat D.	Plat E.	Plat F.	Average.		Increase on unplowed plats.
							Plowed plats.	Unplowed plats.	
1916	33.8	39.8	35.2	37.4	35.9	38.8	....	....	....
1917	0	2.6	3.8	4.9	2.8	5.6	0	3.9	3.9
1918	**10.8**	**16.0**	23.8	26.3	24.0	**20.5**	15.8	24.7	8.9
1919	**15.8**	20.5	**21.8**	22.3	23.8	**19.5**	19.0	22.2	3.2
1920	**17.5**	**21.1**	21.8	**23.4**	29.8	**28.5**	22.6	25.8	3.2
Average, 1917 to 1920	11.0	15.1	17.8	19.2	20.1	18.5	14.4	19.2	4.8

Near these plats in the field are two other rotations that were started in time to be productive of evidence on the same subject in 1919 and 1920. Rotation No. 568 is fallow, winter wheat on fallow, and winter wheat sown in stubble. Rotation No. 580 is the same thing lengthened one year by early plowing the last wheat stubble and raising a third crop of wheat before fallowing. In 1919 the stubbled crop was heavier than either that fallowed or plowed. In 1920 the fallowed was heavier than the stubbled, and the stubbled heavier than the plowed. As has been noted before, 1919 was distinctly unfavorable to methods that prompted a rank growth. In 1920 there was a similar tendency, but it did not go far enough to overcome entirely the initial advantage enjoyed by such methods as fallow.[8]

The somewhat anomalous condition is presented of early plowing or cultivation yielding heavier than late plowing, but no cultivation at all sometimes yielding heavier than either and averaging nearly as much as the best methods of early cultivation. The first is suscep-

[8] In 1921 the yield of the continuously stubbled plat known as rotation No. 591 fell to about one-half that of early plowing, but was still above that of late plowing. In the other experiments described, wheat sown in disked stubble on which plowing had been deferred for a lesser number of years maintained yields as high as on early plowing, or even higher.

tible of satisfactory explanation, but the reasons for the second condition are not so obvious. The stubble affords winter and spring protection to the wheat. It also catches snow during the winter and checks evaporation from the surface during the winter and spring. Then, as has been pointed out in considering the results on fallow, there are years when the heaviest early-season growth does not fulfil its prospects of making the heaviest crop of grain. The seven years covered by this phase of the experiments have embraced an unusual proportion of good wheat years and perhaps an unusual number of years favoring the poorer methods. It is therefore possible that a continuation of these experiments may not show as favorable results for the unplowed plats as has the period under discussion.

The data from the Fort Hays branch station and other field stations on the Great Plains show that in years sufficiently favorable to produce a crop, winter wheat is well able to compete with annual weeds because of the start it has over them in the spring. Spring-sown grains do not possess this ability to anything like the same degree, for the reason that the weeds start with such crops or even in advance of them. On this account plowing is of much greater import to spring-sown than it is to fall-sown grains.

The evidence indicates that on land free from perennial weeds and grasses annual plowing for winter wheat may not be as necessary an operation as has generally been believed.

CORN AND KAFIR AS PREPARATIONS FOR WHEAT.

In 1915 four 2-year rotations were started to compare corn and kafir as preparations for winter wheat and to determine the effect on the yield of wheat of limiting the stand of corn and kafir on the ground by planting only every other row.

Rotation No. 149 is corn ordinarily spaced, followed by wheat on disked corn ground. Rotation No. 150 is the same, but with the rows of corn twice as far apart. Rotation No. 349 is kafir ordinarily spaced, followed by wheat on disked kafir ground; and rotation No. 350 is the same with the kafir rows twice as far apart. Started in 1915 these rotations were in full swing in 1916. Table 10 gives the yield of wheat in these rotations for the 5-year period from 1916 to 1920, inclusive. These yields show a decided advantage of corn over kafir as a preparation for wheat. Limiting the stand of kafir has had a decided effect in increasing the yield of wheat, but with corn there has been little or no such effect.

The yield of wheat following even a one-half stand of kafir has not been equal to that following a full stand of corn. Wheat on fallow in rotation No. 560 adjoining these plats has averaged 20.2 bushels for the same years. This is a gain of 1.5 bushels over ordinary-spaced corn and only 0.3 of a bushel over double-spaced corn, but a gain of

9 bushels over ordinary-spaced kafir and 4.7 bushels over double-spaced kafir. More adequate comparisons of corn with other crops and preparations for winter wheat have been made elsewhere in this bulletin. The object of these rotations is to afford a comparison of corn with kafir and of ordinary spacing with double-spaced plantings of these crops.

TABLE 10.— *Yields of wheat on disked ground following corn or kafir with different spacings at the Fort Hays branch station for the 5-year period from 1916 to 1920, inclusive.*

Year.	Yields per acre (bushels).			
	After corn.		After kafir.	
	Rotation 149, ordinary spaced.	Rotation 150, double spaced.	Rotation 349, ordinary spaced.	Rotation 350, double spaced.
1916	34.1	39.1	15.1	31.1
1917	3.1	3.3	.0	.6
1918	13.3	10.1	1.0	3.8
1919	18.1	18.3	20.6	18.6
1920	25.1	28.6	19.2	23.5
Average	18.7	19.9	11.2	15.5

The ordinary-spaced corn averaged 2.1 bushels of grain and 2,531 pounds of stover. The double-spaced corn averaged 8.8 bushels of grain and 2,286 pounds of stover. The ordinary-spaced kafir averaged 10.7 bushels of grain and 4,748 pounds of stover. The double-spaced kafir averaged 15.1 bushels of grain and 3,627 pounds of stover.

WHEAT IN MISCELLANEOUS ROTATIONS.

In Table 8 were given the yields of wheat on two plats in rotation No. 401 and one plat in rotation No. 402. For comparison with these the yield of wheat on the N–O plats in the methods-of-fallow experiment for the same years is included in the table. Rotations Nos. 401 and 402 were started in the spring of 1913. Spring wheat was sown in them that year, so that results with winter wheat are available for only the 7-year period from 1914 to 1920, inclusive.

No. 401 is a 4-year rotation of kafir listed, fallow, winter wheat on fallow, and winter wheat on early-plowed wheat stubble. The wheat on fallow has averaged 20.7 bushels and on fall-plowed wheat stubble 21.4 bushels. These figures present the interesting evidence of wheat after wheat yielding more than after fallow. The yield of straw supports the evidence of the yield of grain. As these are in a rotation where one follows the other, there is no ground for an argument that one has any soil advantage over the other. The yield following fallow is a little low as compared with that on fallow after kafir in the near-by 3-year rotations Nos. 501 to 510, inclusive, con-

sidered in the following pages, and it is also low in comparison with wheat on alternate fallow in methods of fallow. These latter are in fairly good agreement. It has been shown that kafir has a very depressing effect upon the yield of wheat that follows it immediately, but the evidence as a whole indicates that this effect is eliminated by a fallow. No. 402 is an adjoining rotation of kafir listed, fallow, winter wheat on fallow, and kafir listed. The wheat on fallow in this rotation has averaged only 17.6 bushels. This seems to show that the growth of two crops of kafir in succession establishes a depressing effect that persists through a fallow. This possible conclusion is subject to a reasonable doubt by the yields in 1914, when the rotations had not run long enough to differentiate the wheat on fallow in rotations Nos. 401 and 402, but when the yield of wheat in No. 402 was low.

The kafir following wheat in rotation No. 410 has averaged 22.6 bushels per acre; following wheat in rotation No. 402 it has averaged 20.4 bushels, and following kafir in the same rotation it has averaged only 14.7 bushels. While a potential difference of soil and location might be established between rotations Nos. 401 and 402, the two plats of kafir in No. 402, like the two plats of wheat in No. 401, are grown on the same ground, one following the other from year to year over the four plats that constitute the rotation.

These 4-year rotations were started for comparisons with the 3-year rotations of kafir, fallow, and wheat that are considered in the following pages to determine the effect of lengthening them by introducing a second crop of wheat or a second crop of kafir. Their evidence is very positive. The second crop of wheat (wheat on early-plowed stubble of wheat raised on fallow) has an exceptionally favored position. The rotations should be lengthened by increasing the number of wheat crops. On the other hand, the second crop of kafir (kafir following kafir) is depressed to about two-thirds the yield of kafir following wheat. There is also indication, although the evidence is by no means conclusive, that this doubling of the kafir crop establishes a depressing effect that is not entirely eliminated by a year of fallow.

In 1916 two 4-year rotations were started. Rotation No. 403 is corn on spring plowing, barley on disked corn ground, winter wheat on fall-plowed barley stubble, and winter wheat on fall-plowed wheat stubble. Rotation No. 404 is the same in all respects except that kafir takes the place of corn.

The 4-year average yield of the wheat on fall-plowed barley stubble has been 17 bushels in each rotation. The wheat following wheat has averaged 17.2 bushels in rotation No. 403 and 16.1 bushels in No. 404.

The barley has averaged 23.8 bushels following corn and 22.5 bushels following kafir. These rotations show little or no depression

in the yield of spring-sown barley as a result of its following kafir, which is very contrary to the effect of kafir on fall-sown wheat, as shown in rotations Nos. 149, 150, 349, and 350, which have been considered.

WHEAT IN 3-YEAR ROTATIONS OF KAFIR, FALLOW, AND WHEAT.

In 1913 two series of ten 3-year rotations were started. These 20 rotations are all fallow, winter wheat, and kafir. The first series, numbered from 501 to 510, inclusive, was planned primarily to study methods of raising kafir on wheat stubble, but two of the rotations, Nos. 501 and 502, vary from the others in the method of fallow. The cultivation for fallow in rotation No. 501 is started in the fall by plowing to a depth of 12 to 14 inches with a deep-tillage machine. The plat to be fallowed in rotation No. 502 is dynamited before listing in the fall. A half stick of dynamite is shot at a depth of 3 feet in holes 16 feet apart. The first year 20 per cent dynamite was used, but since then 40 per cent has been used. This plat and the plats to be fallowed in rotations Nos. 503 to 510, inclusive, are listed in late fall. During the spring the lister ridges are leveled by such cultivation as may be necessary to prevent weed growth. About midsummer the plats are all plowed. Enough cultivation is given after plowing to prevent weed growth and to prepare a good seed bed for winter wheat. The fallows are seeded uniformly to wheat in the usual manner, with no special treatment.

These rotations are so arranged that the fallow, wheat, and kafir each occupy a solid block of 10 plats side by side, arranged from north to south in numerical order. The wheat stubble is prepared for kafir in the several rotations as follows:

Rotation 501: Fall list, cultivate ridges down in early spring, list at planting time (deep tilled for fallow).
Rotation 502: Same as No. 501 except dynamited for fallow instead of deep tilled.
Rotation 503: Double-disk in July or August, fall list, cultivate ridges down in early spring, list at planting time.
Rotation 504: Fall list, cultivate ridges down in early spring, list at planting time.
Rotation 505: Fall list, ridges untouched until planting time, then split ridges.
Rotation 506: Fall list, work with harrow in spring, list in same furrows at planting time.
Rotation 507: Fall list, work with harrow in spring, split ridges at planting time.
Rotation 508: Early spring list, ridges untouched until planting time, plant in same furrows.
Rotation 509: Double-disk in spring, list at planting time.
Rotation 510: Untouched until planting time, then list.

The yields of both wheat and kafir in these 10 rotations for the 7-year period from 1914 to 1920, inclusive, are given in Table 11.

Careful study of the data from these and the 10 companion rotations shows the plat variation or experimental error to be so high

in relation to the differences in yield exhibited from the different rotations that for the purposes of the present bulletin only limited consideration and conclusions are warranted.

TABLE 11.—*Yields of wheat and kafir in rotations Nos. 501 to 510, inclusive, at the Fort Hays branch station for the 7-year period from 1914 to 1920, inclusive.*

Year and crop.	Yields per acre for the 10 rotations (bushels).									
	No. 501.	No. 502.	No. 503.	No. 504.	No. 505.	No. 506.	No. 507.	No. 508.	No. 509.	No. 510.
Wheat:										
1914	24.8	24.3	25.5	26.8	26.8	26.7	26.0	24.3	23.9	23.5
1915	14.9	13.5	14.4	12.5	13.9	13.1	14.9	14.4	17.0	15.9
1916	38.8	32.9	35.5	37.8	39.7	40.3	40.5	38.7	37.7	33.2
1917	10.2	14.3	15.0	12.3	14.4	14.6	16.4	15.5	15.3	11.1
1918	6.9	10.8	10.1	11.2	12.8	12.4	12.3	12.9	12.3	12.0
1919	10.9	10.4	10.7	11.0	12.6	12.8	12.3	12.0	10.9	10.1
1920	37.5	39.0	39.3	35.8	37.9	31.2	37.2	37.7	37.5	33.3
Average	20.6	20.7	21.5	21.1	22.6	21.6	22.8	22.2	22.1	19.9
Kafir:										
1914	2.6	5.0	6.4	5.9	5.8	6.6	6.9	8.1	4.8	4.6
1915	47.8	43.3	43.7	48.8	46.9	50.2	35.0	39.8	29.9	30.3
1916	11.8	8.8	10.7	13.8	19.8	15.8	13.7	10.6	7.9	2.6
1917	8.9	2.9	3.4	3.1	1.7	1.8	1.3	.9	.6	.4
1918	14.1	6.8	5.3	4.5	3.3	3.9	4.8	2.5	3.7	2.7
1919	34.5	31.6	32.3	33.5	38.3	46.6	35.2	40.9	38.4	28.4
1920	78.2	62.1	68.5	68.1	68.0	68.0	67.3	63.1	47.6	38.3
Average	28.3	22.9	24.3	25.4	26.3	27.6	23.5	23.7	19.0	15.3

Comparing the yields in rotations Nos. 501 and 502 with those from the other rotations it is very evident that neither the deep plowing of No. 501 nor the dynamiting of No. 502 has been effective in increasing the yields of wheat on the fallow receiving such treatment. The preparation of the wheat stubble for kafir on these plats is the same as in rotation No. 504. Comparing the yields of kafir in Nos. 501 and 502 with that in No. 504 especially and with the other rotations in general, there appears good basis for the conclusion that the deep tillage of No. 501 has some years extended its effect to the kafir crop and increased its yield. Special attention is directed to the yields in 1917, 1918, and 1920, when this effect was shown. By the same comparisons the aftereffect of the dynamite has been to depress the yields of kafir the second year after its use. This may not be the correct interpretation, although the evidence to support it is nearly as strong as that indicating an increase from deep tillage. Passing over the other methods to the last two, it is evident from comparison of them with the others that the yield of kafir is increased by cultivation that prevents the growth of vegetation during the spring before planting. The double-disking in the spring which rotation No. 509 receives is not sufficient to do this, and a marked decrease from the others is noted in its yield. A still further decrease is noted in the yield in rotation No. 510, which receives no cultivation at all until it is planted with a lister. This method is sometimes

almost or quite impracticable on account of the growth of weeds and more especially the growth of volunteer wheat, which reaches nearly or quite the heading stage by the time kafir is planted. In the case of rotation No. 510 this seems not only to have reduced the crop of kafir about one-third, but to have continued through the fallow and some years reduced the yield of wheat grown on it.

The second series of 10 rotations, numbered from 551 to 560, inclusive, was planned to study the use of manure applied directly to the wheat at different rates, applied to kafir at different rates, and the effect of a light dressing of straw on winter wheat.

Except for the manure or straw that they receive, the treatment of all 10 rotations is uniform. The fallow and the wheat on fallow are the same as outlined for rotations Nos. 503 to 510, inclusive. After the wheat is harvested the ground is plowed in the fall, cultivated in the spring, and the kafir planted with shallow listing.

Rotations Nos. 551, 552, and 553 receive no manure and are duplicates run as checks on those receiving treatment.

The winter wheat in rotation No. 554 receives a top-dressing of straw late in the fall at the rate of 2 to 3 tons per acre. To hold it in place, the straw is cut into the ground with a packer.

Barnyard manure is applied as a top-dressing at the same time to the wheat in rotation No. 555 at the rate of 3 tons per acre, and to the wheat in rotation No. 556 at the rate of 6 tons per acre.

In rotations Nos. 557, 558, 559, and 560 barnyard manure is used preceding the kafir crop. It is spread on the plowed land in November or December at the same time the wheat is top-dressed. It is used at the rates of 3 tons per acre in rotation No. 557, 6 tons in No. 558, 9 tons in No. 559, and 12 tons in No. 560.

As with rotations Nos. 501 to 510, inclusive, these are arranged so that the fallow, wheat, and kafir each occupy each year a solid block of 10 plats with the rotations arranged from north to south in the order in which they appear in Table 12. This table gives the yields of wheat and kafir in these 10 rotations for the 7-year period from 1914 to 1920, inclusive.

If it were not for the three check rotations which appear at intervals among the manured ones, one might attempt to discuss the effects of manure applied at different rates and to different crops in the rotations. But with the data as they are, the only conclusion that can be arrived at from a study of the yields year by year and of the average from the entire series of years is the general one that both barnyard manure and straw have been ineffectual in increasing the yields of either wheat or kafir. To one familiar only with soils that respond to manure or on which it is a necessity to crop production, such a result may seem almost incredible, but it is a rather usual one on the Plains and the prairie soils of the dry-farming section. It is recog-

nized, of course, that the length of time these experiments have run is insignificant in comparison with the time these soils will be cropped. Regardless of the conclusions to which it may lead, this work is considered of the greatest importance and will be continued.

TABLE 12.—*Yields of wheat and kafir in rotations Nos. 551 to 560, inclusive, at the Fort Hays branch station for the 7-year period from 1914 to 1920, inclusive.*

Crop and year.	Yields per acre for the 10 rotations (bushels).									
	No. 554, straw on wheat, 3 tons.	No. 551, check, no manure.	No. 555, manure on wheat, 3 tons.	No. 556, manure on wheat, 6 tons.	No. 552, check, no manure.	No. 557, manure on kafir, 3 tons.	No. 558, manure on kafir, 6 tons.	No. 553, check, no manure.	No. 559, manure on kafir, 9 tons.	No. 560, manure on kafir, 12 tons.
Wheat:										
1914	20.2	22.9	26.0	27.0	24.2	25.0	26.2	26.5	27.4	30.3
1915	19.7	17.8	16.1	15.3	14.2	14.5	16.2	19.2	17.4	17.3
1916	32.6	29.4	27.3	33.9	37.0	38.6	38.8	40.8	37.4	35.3
1917	2.2	6.8	6.7	6.8	7.5	8.7	8.9	7.1	8.8	11.8
1918	10.8	11.5	11.2	10.5	10.8	10.4	8.8	11.3	9.5	10.2
1919	12.2	13.6	12.2	13.0	10.6	10.6	12.3	11.6	10.5	11.1
1920	27.3	30.3	29.6	36.0	37.8	38.3	32.9	37.1	33.3	32.7
Average	17.9	18.9	18.4	20.4	20.3	20.9	20.6	21.9	20.6	21.2
Kafir:										
1914	6.8	6.8	4.8	5.5	8.5	7.8	6.9	8.8	9.2	7.7
1915	58.2	55.5	52.8	55.3	54.3	53.4	51.9	50.4	52.3	47.9
1916	7.5	13.8	18.2	11.6	12.1	5.8	2.2	1.3	1.1	.6
1917	0	0	0	0	.1	.2	.1	.2	.2	.3
1918	.2	.4	.4	.4	.4	.5	.5	.5	.5	1.0
1919	28.3	36.3	35.8	37.2	39.7	32.0	27.7	29.6	23.3	22.2
1920	59.5	54.9	59.6	67.7	67.4	63.6	65.3	66.6	70.8	66.3
Average	22.9	24.0	24.5	25.4	26.1	23.3	22.1	22.5	22.5	20.9

In 1919 experiments were started to determine the effect of commercial fertilizers on wheat production. At the same time extensive work was started in further methods of seed-bed preparation for wheat following winter wheat, and a test of the disk and lister drills on the different seed beds. It is too early to draw any conclusions from these experiments.

SUMMARY.

The Fort Hays branch station is located in Ellis County, Kans. This county is in the western tier of the solid block of "million-bushel" wheat counties in that State. Statistics of the Kansas State Board of Agriculture [9] show that the agriculture of this section has been stabilized for 30 years by devoting nearly three-fourths of the cultivated acreage to winter wheat. The statistics also show that during this period there has been no change in yields. The average yield of Ellis County for the 30 years from 1891 to 1920, inclusive, is only 9.6 bushels per acre.

The statistics of crop acreage show that if every acre in other crops were seeded to wheat it would still be necessary to sow approximately two-thirds of the wheat following wheat. About one-half of the other

[9] Kansas. State Board of Agriculture. Biennial Report, v. [3-27], 1874-1919-20. Topeka, 1874-1921.

third, or one-sixth of the total wheat acreage, might be sown following corn, and the other sixth following miscellaneous crops, chiefly grain and forage sorghums. The greatest cultural problem in terms of acres involved, consequently, is how to prepare wheat stubble for wheat.

Results of experiments in methods of wheat production conducted cooperatively at the Fort Hays branch station are available for the 14-year period from 1907 to 1920, inclusive.

During this entire period wheat has been grown continuously after wheat by several methods of cultivation. There are 90 days between harvest and seeding. Late plowing, 73 days after harvest and 17 days before seeding, has averaged 10.5 bushels per acre. This is the lowest yielding method under trial, but is practically the same as the Ellis County average of 10.2 bushels for the same period. Early plowing, 32 days after harvest and 58 days before seeding, has averaged 14.6 bushels per care. Early plowing subsoiled has averaged 17 bushels, and land listed instead of early plowed has averaged 17.3 bushels. Land alternately fallowed and cropped to wheat has averaged 20.3 bushels.

During the 7-year period from 1914 to 1920, inclusive, surprising success has attended the growth of wheat sown in wheat stubble either disked or uncultivated. This method has averaged higher yields than late plowing and nearly as much as early plowing.

The results of the experiments show the possibility of increasing the county average. Land that can be early plowed or listed can not be fallowed profitably, although the yield per acre might be increased somewhat. Land that can not be prepared early could be fallowed more profitably than plowed late and seeded. If free from perennial weeds or grasses it could still more profitably be seeded in the stubble, with no preparation unless perhaps a double-disking.

Studies of the method of fallow and the length of the fallow season show that the effectiveness of fallow is not increased at this station by cultivation for a longer period than the growing season of the fallow year. The greater part of its benefits may be realized by cultivation in the period between harvest and seeding. The essential factor of the fallow is the maintenance of a bare surface, prevention of the growth of vegetation. The cultural methods by which this is accomplished are of minor importance from the standpoint of resultant yield. Their importance is in their relative cost and their effectiveness in preventing soil blowing.

Green manures, although more expensive, do not increase yields over bare fallow or even over early plowing of land from which a crop is harvested.

The results of experiments with sod crops in rotations show them to be relatively unsuccessful themselves. Alfalfa is more successful than brome-grass, but is very depressing in its effect upon following crops. Wheat after corn averages about the same as the better methods of wheat after wheat. Kafir produces heavier yields of both grain and forage than corn, but wheat can not be sown immediately after kafir without great reduction in yield. The depressing effect of kafir is, however, eliminated by a single year of fallow or cropping. Barley, which is spring sown, follows kafir as well as it does other crops and produces relatively good yields. Winter wheat follows barley as well as it does wheat or other crops. This establishes in the rotation a place for barley between kafir and winter wheat.

The use of barnyard manure at different rates and in different positions in 3-year rotations of kafir, fallow, and winter wheat for the 8-year period from 1913 to 1920, inclusive, has not had a measurable effect upon the yields of either wheat or kafir.

The experiments do not indicate that a reduction of the proportion of wheat to other crops would necessarily result in an increased average yield per acre of wheat. They do indicate, however, that the present average yield per acre is not as high as it should be. The most fertile field for the control of yields is the 90-day period between harvest and seeding. The more completely this is made a cultivation period the higher will yields rise above the minimum at which they now rest. An increase of 50 per cent is not impossible, and some part of it should be realized through greater timeliness and efficiency of operations.

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PRODUCERS' COOPERATIVE MILK-DISTRIBUTING PLANTS.

By O. B. Jesness,[1] *Specialist in Cooperative Organization*, W. H. Barber,[1] *Assistant in Marketing Dairy Products*, and A. V. Swarthout, *Investigator in Market Business Practice, Bureau of Agricultural Economics*, and C. E. Clement, *Market Milk Specialist, Dairy Division, Bureau of Animal Industry.*

Milk producers supplying a number of cities have undertaken to solve some of their milk-marketing problems by the establishment of cooperative milk-distributing plants. The objects sought and the conditions which prompted the producers in their actions have been varied. In some instances a number of producers, each delivering direct to consumers, have sought to eliminate the duplication resulting from their individual route-delivery services and to reduce the cost of distribution by establishing a cooperative plant with a centralized delivery system. Difficulty in procuring necessary farm labor has been a factor in some instances in encouraging the establishment of a central plant, since it enabled the producers to devote more time to production.

Ordinances requiring tuberculin testing of all cows or the pasteurization of all milk under strict sanitary regulations of the health department have in some cases made it desirable for producers to establish a cooperative milk-pasteurization plant in order to comply with the city ordinances. In some instances producers have purchased privately owned plants with a view to effecting greater efficiency and economy in handling and distributing their milk supplies. Low prices and alleged unfair treatment from private concerns sometimes have aroused action which has resulted in the establishment of cooperative plants.

Cooperative milk-distributing plants at present are located mostly in small cities where a satisfactory system of distribution had not previously been developed. Milk producers supplying the larger cities usually have organized cooperative associations for the purpose of acting as agents for their members in making contracts for the

[1] Resigned.

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sale of milk to city dealers. To distribute cooperatively a considerable proportion of the milk supply of a large city would require an organization with a large capital. The problem of operating large milk-distributing plants is more complex in large cities than in small cities where the producers are located in the immediate vicinity of the city in which the plant is established.

ESTABLISHING A COOPERATIVE MILK PLANT.

The advisability of establishing a cooperative milk-distributing plant can not be determined without first having obtained complete information as to local conditions. To obtain this information a careful survey of the local situation should be made. This survey should include such important factors as the present marketing methods and conditions, existing marketing facilities, the direct benefits of a cooperative plant to producers, the attitude of the producers, the support likely to be given the enterprise, the volume of business available, means of financing the venture, and such other information as will be helpful in determining the possibilities of success in operating a cooperative plant.

An actual need for a cooperative milk-distributing plant should exist among the producers. A desire and demand for a cooperative plant should be manifested by the producers themselves. Unless the sentiment of the producers is strongly in favor of a cooperative plant, and they feel that a plant is an absolute necessity for the solution of their problems, adequate financial support and sufficient volume of business for successful operation may not be obtained later when needed. Active leadership of a sane and sound character must exist somewhere among the producers, for it will be required in the administration of the business later by the board of directors.

ESSENTIALS FOR SUCCESS.

A first essential for success in a cooperative plant is sufficient volume of business to make economical operation possible. The actual supply of milk pledged for delivery to the cooperative plant must be given careful consideration. If only a small part of the milk produced in the locality is pledged, it may be impossible to operate the plant efficiently and economically. Specific figures can not well be given, but it has usually been found that unless at least two-thirds of the milk marketed locally is pledged to the organization, it is advisable to defer the establishment of a cooperative plant until the necessary support has been obtained.

Efficient management is essential in any business. Especially is this true in cooperative milk plants, because many technical and practical problems must be handled properly to obtain best results. Efficient business methods are essential to good management and an ade-

quate accounting system is indispensable in keeping a check on the business.

A conviction on the part of the members that cooperation, or a working together, will benefit each individually is essential for the success of the organization. The members should understand that as members of a cooperative organization they must give it their moral, financial, and material support, for its success depends directly upon them. Every member should regard the cooperative milk plant as a business enterprise whose success will contribute to his success. Its cooperative features give it no supernatural power that will keep it from failure when it is mismanaged or not properly supported by its members.

Before launching into the operation of a cooperative milk plant, adequate capital for financing it should be assured. Unless the plan of financing will permit the purchase of necessary machinery, equipment, supplies, etc., when the plant is started, provide adequate working capital, and enable additional equipment to be purchased, when needed, during the operation of the plant, sooner or later financial difficulties will be encountered. Complete estimates of the total capital investment should be obtained from reliable sources, and the plan of financing adopted should adequately provide for the raising or securing of the necessary capital funds. Large loans, bonded indebtedness, or other liens against the organization should be avoided. No financial handicap should be placed upon the organization, for the problems to be met may be difficult enough without introducing unnecessary financial ones. In fact, the organization should be started under most favorable conditions and the problems of financing should be solved before the organization enters into the business of milk distribution.

A fifth essential to the success of a milk-distributing plant, is the maintenance of high standards in the quality of the product handled and sold. The raw material received must be carefully produced under sanitary conditions, must be handled by modern up-to-date methods, and sanitary conditions must prevail in the plant. Without high quality in the product, customers are likely to become dissatisfied and the business fail because of lack of patronage.

Another essential is a sound business policy in conducting the business of the organization. Such a policy must be adopted by the board of directors, for without it the manager can not know that his action will meet with the approval of the board. An organization with a board of directors that has adopted a sound business policy may succeed with a mediocre manager, where otherwise it might fail. Likewise an organization with a most competent manager but having a board of directors which will not support a sound

business policy may be doomed to failure. It is obvious that the board should be composed of men with an understanding of sound business principles.

MARKETING CONTRACTS.

In cooperative milk-marketing organizations it has been found desirable for the business relations between the producers and the organization to be clearly defined in a marketing contract. By the terms of such contracts the producers agree to deliver to the organization all the milk produced on their farms, except that required for farm or household use. The organization in turn agrees to sell and distribute the producers' product and to make returns therefor in accordance with specific provisions of the contract. Such contracts tend to give greater stability and permanence to the organization.

METHODS OF FINANCING.

Rather large investment in buildings and equipment are required in cooperative milk plants for the proper handling of milk and milk products. Definite methods of financing must be worked out carefully and adapted to the form of organization to be employed. Cooperative milk-marketing organizations may be financed either with or without capital stock. In nonstock organizations the necessary capital may be obtained from membership fees, cash payments for certificates of indebtedness, or from loans made by the members, while in organizations with capital stock the necessary capital is secured by selling shares of stock. Cooperative milk-plant organizations usually have been formed with capital stock, as producers are more familiar with this method. An equitable plan adopted by some organizations requires each producer to purchase shares of capital stock in proportion to the number of cows milked or the amount of dairy products to be marketed at the plant.

In some organizations both common and preferred stock have been issued. Preferred stock ordinarily is entitled to dividends before any are paid on the common stock. The dividends on preferred stock usually are cumulative, and it is customary to withhold voting privileges from stock of this class. The plan of using both preferred and common stock may be advantageous in some organizations, especially where it is necessary to sell stock to others than the members and the producers wish to retain control of the organization through ownership of common stock. However, it should be borne in mind that all the preferred as well as the common stock of associations that desire to come within the scope of the Capper-Volstead Act must be held by producers.

A number of nonstock organizations have been financed through the sale of certificates of indebtedness. These certificates are sold for cash the same as capital stock. The rate of interest is fixed and date of maturity stated on the certificate. They may be sold to any one, since voting power is limited to members only. Usually the certificates of indebtedness are issued in series which mature in from 1 to 5 or 10 years with amortization coupons attached which mature annually. These certificates are paid with sums deducted monthly from patrons' checks and for which the patrons are issued new certificates annually. The interest on the certificates is considered an operation expense and is paid from the reserve fund established for this purpose.

FORMING THE ORGANIZATION.

If the establishment of a cooperative milk plant appears advisable after a very thorough survey has been made of the local situation, the actual work of forming the organization can be taken up actively. Preliminary meetings of the prospective members should be held and the proposed plans of the organization thoroughly discussed at such gatherings. If the successful establishment of a plant seems feasible, an organization committee should be chosen at a called meeting of the prospective members. This committee should proceed with the formation of the permanent organization, including the drafting of suitable by-laws, a marketing contract, and plans for financing the proposed plant.

Subcommittees of the organization committee may be selected to undertake various lines of work. Thus, there may be a subcommittee on membership and a subcommittee to obtain information on the cost of plant and equipment. The latter committee may find it beneficial to inspect the operation of plants already established. First-hand information regarding methods employed, difficulties encountered, and problems to be met in a new plant will be most useful and valuable.

After the organization committee and its subcommittees have completed their preliminary work, a meeting should be held at which the question of perfecting a permanent organization should be decided definitely. Where it is decided to establish a milk-distributing plant, the various plans submitted by the organization committee should be discussed and approved with such changes as seem advisable. Temporary directors should be elected at this meeting and authorized to proceed to incorporate the organization.

INCORPORATING THE ORGANIZATION.

The committee that works out the organization plans should obtain all information possible relating to the corporation laws of the State in which the organization is being formed, because the plan must fit

the requirements of the law under which the organization is to be incorporated. Many States have one or more special laws providing for the incorporation of cooperative associations, and it is usually advisable to incorporate under a cooperative law wherever practicable.

Laws designed for noncooperative business corporations in many cases are not best suited to cooperative organizations, as such laws generally grant each share a vote and provide for dividends on capital stock. Equal voting rights and privileges in cooperative organizations are important and should be adhered to very closely in forming such organizations.

The exact procedure to follow in incorporating an organization depends upon the provisions of the State law under which the organization is to be incorporated; consequently no general plan covering all details can be given. Legal counsel should be employed in obtaining the necessary legal information and in preparing the papers for incorporating the organization.

The temporary board of directors may serve as incorporators, or a committee may be selected for this purpose.

BY-LAWS OF THE ORGANIZATION.

If by-laws have been approved by the milk producers at the general meeting they should be adopted after the incorporation has been completed. The organization then may undertake the objects for which it was established. The by-laws of a cooperative organization should clearly define the purposes for which it is organized and specifically provide for the management, financing, and conduct of its business. Local conditions and plan of financing and operating the organization should be taken into consideration in preparing the by-laws, in order that they may provide for the needs of the organization.

A suggested form of by-laws which may serve as a guide in the preparation of by-laws suited to the needs of cooperative milk-producers' organizations is given in the Appendix. Changes necessary to adapt them to local conditions and the requirements of State law should be made.

OBTAINING A SUITABLE BUILDING.

One of the first questions to be considered by an association is whether to erect a new plant or to rent a building temporarily until such time as a new building can be erected. Sometimes, when the amount of available capital is limited, it may be well to rent a building, if a suitable one can be found, until the capital necessary for the new building can be raised. One of the important considerations, of

course, will be to ascertain if there is a suitable building available for the purpose. Not every building can be remodeled to fit the requirements of a milk plant, and in some cases the cost would be prohibitive.

The building, in the first place, must be conveniently located. It must be so located that it will be easily adapted to the convenient receiving of the members' milk and the loading and unloading of the delivery wagons. Entrance from at least two sides of the building is desirable. Location in respect to sanitation must also be considered. Good air, good light, and good general surroundings are essential. The floors of the plant should be of concrete, and if the building does not have concrete floors, it should be so constructed that the floors can be concreted. It is important that the foundation be strong. The building must be capable of being so remodeled that a convenient plant arrangement for the conduct of the work can be secured. There are many factors to be considered in selecting a suitable building in which to locate a milk plant and it is usually advisable to obtain the assistance of a man who has had plant experience.

The erection of a new building at the beginning has many advantages and is usually advisable if the capital is available. A new building of modern construction will serve as an advertisement, and if there is much competition it will be found that an up-to-date plant is a big asset. Such a plant will attract the attention of the public and will be a great aid in getting the business established. Visitors to such a plant are well impressed, and in this way new business is more easily procured.

Unless a satisfactory building can be purchased at a saving of at least half of the cost of erecting a new building, together with the cost of the lot, it usually will be better to rent a building temporarily until a new one can be constructed, as the advantage accruing from the proper construction and arrangement of a new building would easily overbalance the difference in cost.

LOCATION OF A MILK PLANT.

If a new building is to be erected, the site should be carefully selected. Whether to erect a plant on an expensive site in the business section of the city or to go further out, where property is less expensive, is an important question to be decided. If much competition is to be encountered, an attractive and prominent location is of value from an advertising standpoint. An attractive plant located in the down-town section of the city or on a prominent street is not only a good advertisement but often results in a large quantity of cash sales at the plant. However, it is not good policy to buy a very ex-

pensive site unless competition and the retail sales at the plant will be of considerable importance. In a small or medium-sized town the site should not cost as much as the building. In general, a site must be selected where good drainage and sewer arrangements can be had, as well as an abundant water supply and electricity for light and power.

The advisability of selecting expensive property in the business section will depend on the local situation. As a general rule, this is unnecessary if a suitable location can be obtained a short distance away at a considerable less cost.

TYPE AND CONSTRUCTION OF BUILDING.

The type of building to be selected of course depends a great deal upon local conditions. It is desirable to have a building that is modern and sanitary in every way, both from the advertising standpoint and as regards economy and public health.

In general, the building should be sanitary and up to date, attractive in appearance inside and out, with a convenient arrangement of floor space. In selecting the materials for construction, local conditions must be considered. A permanent building is essential and a wooden structure is usually not advisable. Whether to use brick, concrete, or some other material will depend somewhat upon the local situation as to cost of materials and labor. Brick, concrete, and hollow tile finished with stucco on the outside and cement on the inside are the most common materials used. All of these materials are comparatively permanent and can be constructed practically fireproof. They are much more desirable than wood, and the cost of upkeep and repair is much less.

The floors in the plant should be of concrete and properly laid. Where cans and trucks are rolled constantly over the floor, iron plates may be embedded in the cement to protect the floor. Drainage pipes should be put in place before the floors are laid and sanitary traps should be installed in such places as will provide good drainage in the various rooms.

Plenty of natural light is essential, and no expense should be spared in providing many windows.

Good ventilation is also essential in a milk plant. While windows may provide satisfactory ventilation in small plants, medium-sized and large plants should have some system of artificial ventilation. This may be accomplished by such devices as exhaust fans, ventilating flues, and ventilating shafts.

The type of building will depend on the site and on the equipment selected. The equipment, therefore, should be selected before the plans for the building are made. It is generally advisable to build

a large plant of about two to three stories, so that the milk may flow by gravity from the various pieces of equipment in the plant. There is very little advantage in having a plant of greater height than two and one-half or three stories unless the site is very expensive. The labor required to operate a plant of several stories is usually considerably greater than in a lower building because of the necessity of having a foreman for each floor. Small plants may be only one story high, and one-story buildings can often be remodeled into a satisfactory milk plant with less labor required for their operation than in the case of a two-story plant.

ARRANGEMENT OF THE PLANT.

The rooms in the plant should be divided and laid out so that the plant operations can be carried on with the minimum of labor and machinery, and so that the milk may be handled in a sanitary manner. Plans should be drawn by a competent architect, showing the layout of the rooms and the location of the machinery and equipment. These plans should be carefully studied, and before the final arrangement is decided they should be submitted to the local health officials for approval.

RECEIVING ROOM.

The milk-receiving room should be separate from the other rooms and should be well screened to keep out flies. This room should be located so that the milk may be conveniently received direct from the producers' trucks. The floor of the receiving room should be on a level with the floor of the ordinary truck. A convenient arrangement is to have the floor of this room elevated about 3 or 4 feet, so that the milk may be readily received and dumped into the weigh can, from which it may flow by gravity to a receiving vat. If this is not feasible, the receiving vat may be lowered below the floor level. The receiving room should contain scales, weigh can, sample jars, etc. In the receiving room or in an adjoining room facilities for properly washing and sterilizing the cans should be provided, so that the cans may be returned to the producers in good condition. Apparatus of ample size should be provided for cleansing the cans quickly and thoroughly.

WASHING AND STORAGE ROOMS FOR BOTTLES.

The bottle-washing room should be so located that the empty bottles can be received as conveniently as possible from the delivery wagons. This room should be of ample size to provide space for the bottle-washing machine and plenty of room for the workmen. Where the bottles are held for a time before washing, the room must be

larger than where the bottles pass directly from the delivery wagons to the bottle washer.

A clean bottle-storage room is of considerable advantage for storing bottles after washing. This room should be located between the bottle-washing room and the bottle-filling room. In this room the bottles are allowed to remain after washing until cooled, when they may be filled. It is important that there be no congestion either at the milk-receiving door or the door where the empty bottles are received. Therefore, these two doors should be widely separated.

PROCESSING ROOM.

The milk-processing room may contain the pasteurizing equipment and the bottle-filling apparatus, or the bottle filling may be done in a separate room. Where a bottle-storage room is not provided there must be space in the filling room for the empty washed bottles. A convenient arrangement may be accomplished by having the pasteurizing equipment on a half-story or raised floor, so that the milk may flow from it by gravity through the cooler to the bottle-filling apparatus. On the floor above should be placed the milk-storage vats. Gravity flow of milk is preferable to the use of milk pumps. The only milk pump required with an elevated-floor arrangement is one to raise the milk from the receiving tank on the ground floor to the storage tank above.

MILK-STORAGE ROOM.

A well-insulated milk-storage room is necessary in all milk plants. This room should be insulated with about 4 inches of cork, with cement on the inside and outside. It should be located so that the milk may pass directly into it from the bottling room and, at the same time, be convenient for loading the delivery wagons. The door should swing outward, in order to save refrigeration space, and it is well to have the room as nearly square as possible. The size of the room will depend on the quantity of milk to be stored. There should be enough room to store conveniently all the milk of one day's run with convenient working space.

The following are the approximate sizes of milk-storage rooms required for plants handling various quantities of bottled milk.

Quantity of bottled milk handled.	Size of room.
Gallons.	*Feet.*
300	8 by 8
500	10 by 10
1,000	12 by 15
2,000	18 by 20
4,000	24 by 30

A convenient arrangement for loading the delivery wagons may be provided by having small doors placed in the outer wall of the milk-storage room, so that the wagons can be loaded directly at these doors. To do this the room should be placed next to an outer wall, with driveway for the delivery wagons.

EQUIPMENT OF THE PLANT.

Equipment for a milk plant must be carefully selected. In some cases used equipment can be purchased, but it is usually not a good plan to buy secondhand equipment unless it is in very good condition. When a business is taken over, or when several small dealers combine, considerable used equipment is usually available. However, much of this equipment may not be suitable or of the proper size or capacity, and it may be better to sell or discard it than to try to use it. Some of the equipment may be used for a short time until new equipment can be obtained; for example, a small bottle washer may be used until a larger and more suitable one can be purchased. Usually pasteurizers and bottle-filling machinery should be bought new, and much care should be used to procure the best available. Of course, secondhand bottles, cans, cases, etc., can be used. The advice of persons of experience is necessary when the purchase of secondhand equipment is contemplated or when new equipment is selected. The following are some of the points to be considered in selecting milk-plant equipment:

(1) Simplicity. The number of working parts should be as few as possible to do the required work efficiently.

(2) Ease of cleaning. There should be a minimum of inaccessible parts, for they make daily cleaning difficult.

(3) Ease of sterilizing. It is important that all milk apparatus be sterilized daily. The more easily this can be done the more likely it is that the work will be done properly.

(4) Ease and economy of operation. Unless a machine can be operated economically, it will be a liability to the user rather than an asset. If it can be operated easily much less attention will be required.

(5) Durability. Apparatus of poor quality usually is most costly in the end; durability is an important factor.

(6) Initial cost. While cheap apparatus may cost the most in the end, it is not always necessary or advisable to buy the highest-priced equipment.

(7) Efficiency. In the case of pasteurizers, efficiency in holding the milk at a certain temperature should be considered. It is very important in pasteurization that the milk be positively held at 145° F.

for 30 minutes. It is important that equipment of ample capacity to handle the maximum output of the plant be selected. However, the pasteurizers should not be so large that they will wear out and depreciate before the business is developed to the point that large-capacity equipment is required.

For small plants the work must be so arranged that men can be shifted from one kind of work to another, while in larger plants more specialization in the plant operations can be maintained. For this reason the equipment in small plants must be large enough to permit the pasteurizing and bottling to be done in from two to four hours, leaving the remainder of the day for other work.

LISTS OF EQUIPMENT.

Below are lists of the principal equipment required for milk plants, grouped as follows: (1) Small plants, less than 250 gallons daily; (2) medium-sized plants, 250 to 1,000 gallons daily; and (3) large plants, over 1,000 gallons daily.

(1) Equipment for small plants (less than 250 gallons):
- Platform scale (double beam).
- Temperature recorder.
- Pasteurizing vat (100 to 300 gallons capacity).
- Tubular cooler (if milk is cooled in the vat, cooler may be eliminated).
- Small bottle filler (a filler designed to fill four bottles at a time is satisfactory).
- Bottle washer (consisting of a turbine brush with rinser and steamer).
- Bottle cases (about two sets of cases will be required).
- Cans (cans for delivery of milk to wholesale trade; farmers should provide cans for bringing the milk to the plant).
- 10 to 15 horsepower boiler.
- 3 to 5 horsepower motor.
- Brine tank.
- Can wash sink with steam jet.
- Small separator (about 2,000 pounds per hour).
- Small churn (100 pounds butter capacity).
- Milk storage room (a room of about 6 by 8 feet provides enough space to store one day's supply of bottled milk).
- Babcock tester (12-bottle size).
- Steam and water hose with fittings.
- Steam and water piping.
- Milk pump (if gravity is used no pump is required).
- Sanitary milk piping and fittings.
- Belting, shafting, pulleys, hangers, etc.
- A supply of bottles, caps, washing powder, coal, etc.

(2) Equipment for medium-sized plants (250 to 1,000 gallons):
- 5-beam platform scale or a dial scale.
- 2-compartment weigh can.
- Receiving vat (200 to 400 gallons capacity).
- Sanitary milk pump (capacity 6,000 pounds per hour).

(2) Equipment for medium-sized plants—Continued.

Clarifier (6,000 to 8,000 pounds per hour). This may be eliminated if a satisfactory filter or strainer is provided.
Sanitary milk piping and fittings.
Pasteurizing and cooling outfit (capacity about 4,000 pounds per hour, including recording thermometers and temperature control).
1 or 2 automatic fillers and cappers (separate filler for buttermilk should be used).
1 hydraulic bottle washer.
1 small bottle washer with turbine brush.
1 can washer, rinser, steamer and dryer.
1 forewarmer.
1 separator (2,000 to 4,000 pounds per hour).
1 combined churn and butter worker (churning capacity 150 gallons of cream).
1 butter printer, etc.
1 vat with coil, for buttermilk (about 300 gallons).
1 starter can.
1 300-gallon cheese vat.
1 drain rack.
Trucks and conveyor track.
1 5 to 10 ton refrigerator outfit with brine tank, brine pump, etc.
1 steam boiler (20 to 40 horsepower).
Motors (10 to 20 horsepower).
1 steam engine (12 to 20 horsepower). Direct-connected motors may be used on some of the machinery and if desired all power may be provided by motors.
Chemical and bacteriological apparatus.
Cans.
Bottle cases.
Shafting, belting, hangers, pulleys, etc.
Steam and water piping and fittings.
Steam and water hose and fittings.
Supplies of bottles, caps, washing powder, etc.

(3) Equipment for large plants (more than 1,000 gallons).

5-beam platform scales or dial scale.
1 can drainer.
1 double-compartment weigh can or quick-dumping weigh can.
2 receiving vats (400 to 600 gallons each).
Sanitary milk pump.
Sanitary milk piping and fittings.
1 forewarmer.
1 or 2 clarifiers (8,000 to 12,000 pounds capacity) or an efficient filter.
1 or 2 insulated milk-storage tanks.
1 or 2 separators (8,000 to 12,000 pounds capacity).
Pasteurizing and cooling outfit (capacity 6,000 to 10,000 pounds per hour), including recording thermometers and temperature control.
1 small pasteurizer for cream.
1 small tubular cooler.
2 to 4 automatic fillers and cappers.
1 large hydraulic bottle washer.
1 small bottle washer with turbine brush.
1 can washer, rinser, steamer, and drier.

(3) Equipment for large plants—Continued.

- 1 combined churn and butterworker (churning capacity 300 gallons of cream).
- Butter printer, ladles, packers, etc.
- Trucks and conveyor track.
- 1 starter can.
- 1 special exhaust-steam heater and storage tank (to supply hot water for pasteurizing and washing purposes).
- 1 300 to 600 gallon ripener.
- 1 to 2 cheese vats (300 gallons capacity).
- 2 drain racks.
- Curd knives, curd pails, paddles, and whey strainer for cottage-cheese making.
- Buttermilk vats (300 to 800 gallons capacity).
- Refrigerating equipment (20 to 40 tons), with compressor, condenser, brine tank, brine pump, and all necessary piping and fittings.
- Boilers (60 to 200 horsepower).
- Engine (40 to 80 horsepower).
- Motors (30 to 100 horsepower).
- Milk cans, bottles, and cases.
- Belting, shafting, pulleys, hangers, steam and water piping and fitting, etc.
- Chemical testing apparatus.
- Bacteriological testing apparatus.

OFFICE EQUIPMENT.

Besides the equipment listed, office equipment will be required. Small plants require only a desk with chairs and possibly an adding machine, check protector, and a safe. Large plants require, in addition, typewriters, computing machines, addressing machines, filing cabinets, and most of the equipment required in a modern business office.

DELIVERY EQUIPMENT.

The delivery equipment required depends on the kind of trade served and its accessibility. Automobile trucks often may be used economically in serving wholesale trade. Where considerable territory has to be covered and for very scattered retail trade the automobile may be used economically. Use of horse and wagon, however, is the most common and satisfactory method of delivering to retail trade. It has many advantages over the automobile. One man can deliver a load of milk from a horse-drawn wagon, but usually at least one extra man will be required on an automobile truck. The constant stopping and starting necessary on a retail milk route is not favorable to the use of an automobile for such delivery, although recently electric-driven trucks are giving economical service.

The quantity of goods that can be delivered from a wagon or truck depends primarily on how scattered the trade is, the method

of delivery, whether many flights of stairs must be climbed, etc. In the ordinary city, where there is more or less competition, about 250 to 300 quarts of milk, with the usual quantity of cream and other dairy products, are commonly carried on a retail wagon. For wholesale trade one delivery outfit will handle 500 to 1,500 quarts, depending on the type of streets, distance apart of the customers, and similar factors.

INVESTMENTS IN PLANT AND EQUIPMENT.

If a building is rented or bought it must be remodeled to fit the requirements of the business and this remodeling will cost, depending on the size and condition of the building, from $500 to $5,000 or more. The rental of a building will, of course, depend upon local conditions, location in the city, on size of building, etc., but this will usually vary from $30 to $150 per month.

The money that must be invested in a new building will depend on the quantity of milk to be handled, materials of construction used, cost of labor, local conditions, etc. Table 1 shows the investments in plant building at 27 representative producers' milk plants of various sizes located in various cities throughout the country. While there are wide variations in cost, caused by lack of standardization of buildings, varied materials used, and other factors, these figures will give a general idea of the approximate amount of money that will have to be invested in a building.

The cost of milk-plant equipment depends on the quality and size and the cost of transportation. In Table 1 are also shown the investments in plant equipment in 27 producers' cooperative plants of various sizes.

TABLE 1.—*Investments in plant and equipment at 27 producers' cooperative milk plants, arranged according to quantity handled.*

Size of plant (gallons handled daily).	Number of plants.	Average number gallons handled daily.	Investment in plant.		Investment in plant equipment.	
			Average per plant.	Average per gallon.	Average per plant.	Average per gallon.
500 gallons or less	9	413.9	[1] $10,000.00	[1] $25.97	$11,811.21	$28.73
501 to 1,000 gallons	7	793	[2] 18,977.87	[2] 22.77	25,208.68	31.79
1,001 to 2,000 gallons	5	1,760	[2] 22,515.76	[2] 11.69	[3] 20,933.77	[3] 11.89
2,001 to 8,000 gallons	6	4,199.66	94,750.25	19.14	60,960.15	12.34
	27	1,602.7	36,339.02	19.45	26,624.28	16.97

[1] Only 5 plants in this group had buildings of their own.
[2] One plant in this group rented a building.
[3] One plant in this group handled mostly all wholesale.

TABLE 1.—*Investments in plant and equipment at 27 producers' cooperative milk plants, arranged according to quantity handled*—Continued.

Size of plant (gallons handled daily).	Number of plants.	Investment in delivery equipment.		Total investment.	
		Average per plant.	Average per gallon.	Average per plant.	Average per gallon.
500 gallons or less	9	$2,893.75	[1] $6.66	[2] $21,433.44	[1] $51.70
501 to 1,000 gallons	7	11,185.79	14.07	[3] 49,985.43	[3] 63.04
1,001 to 2,000 gallons	5	7,146.06	[4] 4.33	[3, 4] 49,482.13	[3, 4] 28.11
2,001 to 8,000 gallons	6	19,475.25	5.21	[5] 155,136.34	[5] 36.97
	27	8,556.39	7.02	63,749.18	39.54

The average investment in plant buildings at 84 privately owned plants ranging in size from 100 gallons to over 10,000 gallons daily was $24,183, and the average investment per gallon handled daily was $13.27 based on 1916 prices. See U. S. Department of Agriculture Bulletin No. 849.

The average investment in plant equipment at 125 privately owned plants ranging in size from 100 gallons to over 10,000 gallons daily was $24,475, and the average per gallon handled daily was $11.59, based on 1916 prices. See U. S. Department of Agriculture Bulletin No. 890.

[1] One plant in this group had no delivery system.
[2] Only 5 plants in this group had buildings of their own.
[3] One plant in this group rented a building.
[4] One plant in this group handled mostly all wholesale.
[5] Two plants in this group had no delivery system.

Below are estimates of the approximate cost of the principal plant equipment for plants of various sizes. These figures include the cost of the principal equipment required, together with an initial supply of cans, bottles, cases, etc.

100-gallon plant, $1,500 to $2,000.
500-gallon plant, $4,000 to $6,000.
1,000-gallon plant, $15,000 to $25,000.
2,000-gallon plant, $25,000 to $35,000.
4,000-gallon plant, $45,000 to $60,000.

The following is an estimate of the cost of delivery equipment, not including stable or garage.

100 gallons, $500 to $700.
500 gallons, $3,500 to $4,000.
1,000 gallons, $5,000 to $8,000.
2,000 gallons, $10,000 to $15,000.
4,000 gallons, $20,000 to $30,000.

In Table 2 are given estimates of the amounts of money required to establish and operate plants of various sizes. While these figures show great variation, a general idea of costs may be obtained from them.

TABLE 2.—*Estimated amounts of money required to establish and operate plants handling various quantities of milk daily.*

Number of gallons to be handled daily.	Building.	Rent of building per month.	Plant equipment.	Delivery equipment.
100 to 250	$1,500 to $6,000	$25 to $50	$1,500 to $5,000	$500 to $2,000
250 to 500	4,000 to 10,000	40 to 75	3,000 to 8,000	1,200 to 3,500
500 to 1,000	10,000 to 18,000	60 to 100	6,000 to 20,000	2,500 to 7,000
1,000 to 2,000	15,000 to 25,000		15,000 to 35,000	5,000 to 14,000
2,000 to 4,000	18,000 to 50,000		25,000 to 50,000	10,000 to 28,000

TABLE 2.—*Estimated amounts of money required to establish and operate plants handling various quantities of milk daily*—Continued.

Number of gallons to be handled daily.	Office equipment.	Working capital.	Total.
100 to 250	$50 to $300	$300 to $750	$3,850 to $14,050
250 to 500	200 to 600	750 to 1,500	9,150 to 28,600
500 to 1,000	500 to 1,000	1,500 to 3,000	20,500 to 49,000
1,000 to 2,000	1,000 to 1,800	3,000 to 6,000	39,200 to 81,800
2,000 to 4,000	1,500 to 2,500	6,000 to 12,000	60,500 to 142,500

For detailed information regarding construction, arrangement and equipment of city milk plants see U. S. Department of Agriculture Bulletins Nos. 849 and 890.

MANAGEMENT OF MILK DISTRIBUTING PLANTS.

The success of business organizations is largely dependent upon competent management. A milk-distributing plant is no exception to the general rule. In fact, milk distribution is a business of many details and success is dependent upon the ability of the manager to organize and conduct the business so that every detail is properly performed.

In cooperative milk-distributing organizations, the necessary legal and supervisory authority is vested in the board of directors, who are elected by and from the members or stockholders. The business management and supervision of the milk-distributing plant is intrusted by the board of directors to the business manager. Where the business is large and it is impossible for the manager to supervise personally each operating branch, superintendents, foremen, or managers of the various departments are employed. Thus the operation of a milk-distributing plant may be divided into such departments as buying, receiving, processing, bottling, manufacturing, accounting, and sales. In such an organization of the business of a milk-distributing plant, the manager must have superior executive and administrative ability, so that the highest possible standard of efficiency may be obtained in each department and each department's activities correlated with the others, to the end that a unified, systematized, efficient operation of the entire business may prevail.

QUALIFICATIONS, DUTIES, AND RESPONSIBILITIES OF MANAGERS.

The qualifications for a milk-plant manager in education, training, and experience depend in a large measure upon his duties and responsibilities, which necessarily vary with the size of the business. Ordinarily, he is expected to formulate the policy and basis for determining prices at which different grades of milk, cream, and by-products are to be sold to different classes of trade. The manager

should obtain all available information regarding the present and prospective local market demands and sources of market supply. He should formulate and execute plans for the most economical methods of collecting, processing, and manufacturing by-products, and of selling and distributing the products of the plant. In order that he may justly be held responsible for the successful conduct of the business as a whole, he should have authority to employ and discharge all labor.

In small and medium-sized plants, where it may be necessary for the manager to give direct personal supervision to the many minor details, and where he may be required to put his hand to any task, it is obviously desirable for him to be thoroughly experienced and able to handle every physical and mechanical detail. In larger plants the responsible supervision of the detail work in the milk-handling department is intrusted to a plant superintendent or foreman, and the larger duties of the manager are executive and administrative, having to do more with questions of business policies which require a knowledge and training in business administration than with factory detail which requires technical training supplemented by factory experience. It is always desirable that the manager have an extended knowledge of, and be familiar with, detail plant operations, in order that he may be fully conversant with the problems of the various departments of the business and be able to formulate plans and policies with the various superintendents for the more efficient and economical conduct of their departments.

The duties of a milk-plant manager in small plants obviously may be numerous and varied, while in larger plants they become more executive in character, with the routine and detail duties performed by other employees. In small plants the overhead costs, including salaries of manager and employees, must be kept at a minimum; hence the manager may be obliged to perform much manual labor in addition to supervising the work of other employees.

The manager of a milk-distributing plant has perhaps greater responsibilities than any other employee. In small plants he is obliged to assume full responsibility for all work done, while in larger plants this responsibility may be shared with the superintendents and foremen.

The manager in every plant, whether large, medium, or small, must be in close touch with each operating department, for responsibilities can not be assumed safely unless the activities of the departments are conducted in accordance with well-defined policies. He must also have access to reports or records of the entire business, in order to formulate plans and policies for its successful conduct.

SELECTING A MANAGER.

In considering the employment of a milk-plant manager, his qualifications in reference to all factors which make for the success of a milk-distributing plant should be considered. Where the organization is newly formed and a plant must be constructed and equipped, it is usually desirable to employ the manager early, so that his advice in matters of arrangement and equipment may be obtained and that he may have ample time to determine upon best plans and policies for the conduct of the business before it is undertaken.

In selecting a manager due consideration should be given by the board of directors to the local conditions and problems to be met. Previous successful experience along business lines of the same or a similar character is a valuable asset, as are dairy-school training and a knowledge of the manufacture of by-products.

The employment of a manager largely because he is willing to accept a lower salary than others is a mistake to be avoided. Quality of service and price should be as much coordinated in the person of a competent manager as in the product produced and sold by the milk-distributing plant. Experience in the sale or manufacture of milk by-products, such as butter, cheese, ice cream, and condensed milk, does not necessarily qualify a man for the position of manager of a market-milk distributing plant. Milk by-products are less perishable than milk and their sale does not involve such a highly organized house-to-house distributing system as market milk. By-product marketing does not often afford experience in retail-route administration nor in the intensive development of new business such as is required in a milk plant. Competent milk-plant managers are in active demand everywhere. In small plants they receive salaries of $6 to $10 per day or above, which in fact are scarcely above those of capable workmen, whose responsibilities may be considerably less. Managers' salaries in large plants range from $2,400 to $6,000 and above per annum (either straight salary or salary and commission) and are based not so much on the size of the business as on the results or success obtained.

Frequently such agencies as the State colleges of agriculture, State dairy and food commissioners, the United States Department of Agriculture, dairy and creamery equipment and supply houses, and dairy trade journals have knowledge of persons capable of managing milk plants and are able to give assistance in locating them. They also may be secured from the ranks of successful small-plant managers or department superintendents in large plants.

PROBLEMS IN OPERATING MILK-DISTRIBUTING PLANTS.

The foregoing statement regarding the duties and responsibilities of a milk-plant manager indicates that he may have many problems with which to deal. For the purpose of separate discussion of the more important phases of each, they will be considered under the following classification:

(1) The securing of an adequate and proper milk supply.
(2) Efficient and economical plant operation.
(3) Sales policies and methods of market distribution.

As consideration is given to each of these, it is well to keep in mind that the manager is responsible to the board of directors, and he should cooperate with it on all matters involving business policies and seek to obtain counsel and advice in formulating them.

THE SECURING OF AN ADEQUATE AND PROPER MILK SUPPLY.

Three problems arise in every milk plant, in obtaining a milk supply. These are (1) source of an adequate supply, (2) maintaining proper quality in the supplies received, and (3) determining upon an operating policy which largely eliminates financial risks and losses.

In cooperative plants, the larger part of the supply is usually received from the patron members, but usually not to the entire exclusion of the product of nonmembers. A closed organization against nonmembers is often not desirable, even though patron members may be able to furnish an adequate supply. By providing a satisfactory market for dairy products, *the establishing of competing plants is discouraged* and production is encouraged. In practically every plant it is necessary to operate a by-products department, in which the surplus supplies may be manufactured into butter, cottage cheese, and other products. Although by-products may be sold ordinarily at lower net prices and on narrower margins than market milk, the overhead costs of the plant may be reduced by increasing the volume of product handled. Also, the handling of a surplus allows opportunity for expansion of sales in the milk department.

To obtain adequate supplies of milk of highest quality, country collecting routes are often employed in reaching patrons in neighboring sections, and receiving and cooling stations are operated at points from which delivery is made by rail or by motor truck. Certain advantages are often obtained by the operation of collecting routes, for the milk is picked up at the farm and needless duplication in delivery by individual producers is eliminated.

The ordinary charge for collecting, which includes the return of empty cans, may range from 1 to 5 cents per gallon, depending upon local conditions.

Closely related to the problem of obtaining an adequate supply is that of maintaining proper quality in the supplies received. Much may be accomplished in improving the quality of the supply received by educational work among the producers and by offering incentives in the price paid the farmer for the production of the better qualities. Constant attention, both at the plant and on the farm, should be given to the quality of milk furnished by each producer, and frequent tests should be made to determine the purity and butter-fat content. Premiums based upon the butter-fat content, absence of sediment or visible dirt, and low bacterial count may be used to encourage delivery of highest quality. The written contracts entered into by the organization and its producers may specify the temperature to be maintained and time of delivery, as well as the time, frequency, and basis of payment.

The consuming public is coming more and more to appreciate high quality in dairy products and is demanding it. Poor quality is frequently the cause of loss of patronage and failure of milk-distributing plants. High quality is the first essential in obtaining and maintaining patronage. It begins at the farm and must not be neglected either there or at any point between the producer and consumer. Good quality and good service are essential to obtaining an increased business.

In cooperative milk-distributing plants the problem of determining upon a satisfactory price agreement with the producer should not be difficult, since price policies are largely determined by the board of directors in conference with or as representatives of the patron members. Furthermore, an agreed margin between producer and consumer prices may be established and any surplus arising may be distributed back to the producers on a pro rata basis, or, what is perhaps better, the plant may be operated on a net-return basis.

Although at some producers' cooperative milk-distributing plants the practice of purchasing the milk from the producer at a stipulated price is followed, the plan of prorating the proceeds for certain periods to the patrons in accordance with raw materials furnished, after deducting necessary charges for operating expenses and reserve, is to be preferred. The producer who realizes that he is a part of an institution which is truly cooperative should be in hearty accord with this method. If the milk is purchased outright at a definite price, the margin between this price and that charged the consumer on account of unforeseen conditions may not be sufficient to provide for the expense of operation. It is impossible at times to foretell how much of the milk delivered during any month will be required for the whole-milk trade and how much must be manufactured into by-products. While an organization that purchases the milk from

the producer might suffer a loss under such circumstances, the producer would not be a gainer, because, being a part of the organization, he would have to bear his part of the loss eventually.

The advantages of the truly cooperative method of payment, that is, prorating the net proceeds in accordance with raw materials furnished, should be carefully considered, for under this method questions of surplus milk may be adjusted without difficulty. Furthermore, the prorating of net proceeds has been employed successfully by many other cooperative organizations, such as cooperative creameries and cooperative fruit and vegetable marketing organizations, and should be equally satisfactory when used in cooperative milk-distributing plants.

EFFICIENT AND ECONOMICAL PLANT OPERATION.

Internal economy in plant operation is a detail feature of business management largely dependent upon the systematic organization, ability, and ideals of the employees, the arrangement and construction of the plant, and the arrangement, capacity, and efficiency of the equipment. The importance of proper plant construction and equipment has been previously discussed and should not be overlooked in the construction and equipment of new plants or the remodeling and equipment of old ones.

Systematic plant organization, with competent, able, and willing employees, is an important factor in obtaining efficient and economical plant operation. Every part of the work should be properly coordinated, to the end that needless waste of supplies and labor may be eliminated. Plants of sufficient size to warrant the employment of a plant foreman or superintendent should have one. The duties of a plant foreman or superintendent are largely supervisory, directing the employees in the plant in the proper performance of their duties, whether it be in weighing, testing, or inspecting the supplies received, pasturizing and bottling the milk and cream, and washing and sterilizing the bottles, vats, or plant equipment. In plants where a plant engineer is not regularly employed, he supervises the proper operation of the boiler, engine, motors, and refrigerating equipment, and whatever detail work is done in the holding of products in the refrigerator or cold-storage room for delivery on routes, or in the manufacture of by-products. It is obvious that competent supervision with systematic organization and high ideals are essential for the most efficient and economical operation of a milk plant.

SALES POLICIES AND METHODS OF DISTRIBUTION.

Local market conditions must be the chief deciding factor in determining the sales policies and methods of distribution in a milk-distributing plant. Quality, however, should be the first considera-

tion in the sales policies. A deep cream line on bottled milk and the thickness or viscosity of bottled cream are important factors in developing new business. A deep, distinct cream line often outweighs all other considerations with consumers, since to them it is a visible and tangible evidence of quality and a daily indication of the business standards of the company. It therefore is important not to diminish the cream line on the bottled milk by the adoption of a low butter-fat standard or by the selection of poor pasteurizing equipment or by improper processing methods.

In establishing a new plant it is important that outlets of sale be developed and methods of distribution be determined before delivery equipment is purchased or contracts for large supplies of milk are made. In this matter it is well to proceed carefully and cautiously, for if complete equipment for an extensive system of retail distribution be purchased and it is later found advisable to employ largely a wholesale system through retail stores, not only will much of the equipment be unnecessary, but it will not be suitable for wholesale delivery. A thorough canvass of the market situation should be made, including the trade demands and requirements, and when profitable outlets are doubtful the establishment of the plant should be postponed until they are assured.

A nucleus for retail and wholesale business may be secured by consolidation of routes discontinued by the patron members or by the purchase of the business and good will of independent dealers. The initial operation of a milk-distributing plant is usually the most critical period in its existence, and failure to solve the problem of sales organization and methods may result in insolvency unless adequate capital has been provided to carry the organization along until sufficient sales business has been developed to cover the heavy overhead costs and make possible the development of a profitable business.

The channels of distribution may be classified as follows:

(1) Direct to consumer by house-to-house delivery.
(2) To consumers through retail stores.
(3) To consumers through hotels, cafés, refreshment stands, etc.
(4) To other dealers who may employ the previously mentioned channels.

The direct-to-consumer channel of distribution by house-to-house delivery is most expensive, although a larger cash return is obtained, as higher prices are charged, and usually a larger permanent business may be obtained, since a satisfied customer may be made a permanent one. Then, too, delivery direct to consumers' doors eliminates certain competition which may result from sales to retail stores. Direct-to-consumer delivery has certain obvious advantages, and where the

retail-route organization may be perfected to the point of permitting large loads (350 to 450 quarts) the overhead costs may be reduced to a minimum.

Distribution through retail stores is a channel employed wholly or in part by milk-distributing plants in many cities. Its advantages are lower costs of delivery expense and usually lower prices to consumers, especially at cash-and-carry stores. Its disadvantages consist of increased competition in selling, and the inconvenience, time, and effort required by consumers to obtain their daily supplies.

Hotels, restaurants, cafés, and refreshment stands ordinarily buy both bulk and bottled goods at wholesale prices, which range lower than retail prices.

Sales to other dealers, who operate either or both retail and wholesale routes, is a method of distribution employed by some milk plants. Such sales are at wholesale and may be made to independent dealers.

Economy in retail-route distribution is dependent upon reduction of route mileage and increase in size of load handled by each route man and upon the extent that the sales organization is able to obtain greater efficiency. Endless duplication of equipment, excessive overhead expense, and needless street travel by many route men of competing distributing plants have been pointed out as a great waste in milk distribution. This could be eliminated by a centralized system of distribution, with one plant handling the city's entire supply.

The average load carried on retail routes averages usually from 250 to 300 quarts per day, while in exceptional cases as many as 350 to 400 quarts are delivered from one retail wagon. However, it is entirely possible for one route man, serving all customers on both sides of the street in closely settled sections of cities, to average 400 or more quarts daily.

An efficient delivery system is just as important to the success of a milk plant as is the quality of its products. Retail routes are usually operated by a delivery man using a one-horse retail wagon or a light motor truck. A retail delivery man, under ordinary conditions, is able to supply 200 to 400 customers a day. Four to 10 routes are generally supervised by a route foreman, and in large companies a sales manager supervises the work of the foremen. Credit men, solicitors, collectors, loaders, and checkers are employed in some delivery organizations.

In larger milk plants, operating five or more routes, it is commonly advisable to place the delivery system under the supervision of a sales manager, with route foremen in charge of a number of routes, say from 5 to 10. The sales manager supervises the route foremen and such additional employees as solicitors and collectors, while the plant superintendent supervises the loaders and checkers.

In small plants the general manager assumes the responsibility of the sales manager and depends upon the plant superintendent to supervise the loaders and checkers and the route foremen or route men for the proper delivery service.

In the larger plants wholesale milk is generally sold on routes that handle wholesale orders exclusively, and retail milk is distributed on exclusively retail routes. Although both the wholesale and retail routes may cover the same territory, separate deliveries are made, because a different kind of service and different hours of delivery are required by wholesale and retail trade. The separation of wholesale and retail sales also simplifies accounting, balancing of load sheets, and the checking of returned bottles and cans. In smaller plants the routes usually handle both wholesale and retail milk on the same wagons.

In cities located in the northern part of the country daylight deliveries are made throughout the spring, fall, and winter seasons, and in the summer deliveries are usually made before daylight. Where one company handles practically all the city distribution, it may be possible to maintain a system of daylight delivery throughout the year. In some southern cities it is customary for milk dealers to make two deliveries a day.

ROUTE SALESMEN AND DELIVERYMEN.

The success of any mercantile business depends upon its ability to sell goods. The successful sale of milk through milk plants depends upon the efficiency of its sales methods. After the general sales policy of a milk plant is approved by the board of directors the manager must determine the methods to be employed in putting it into operation, while the actual selling is intrusted to the sales and delivery organization.

The route men of a modern milk company are more than delivery men. They are, in fact, business representatives who by their relations to the customers, by their speech, and by their personal appearance express the general attitude of the company toward the public in business standards and business ideals. Good will may be either developed or destroyed by the employment of the right or wrong kind of route salesmen.

Route salesmen and delivery men may come from many different sources. They may vary in age from 18 to 45 years, may be inexperienced, with great or small capacity for self-development; or they may, on the other hand, be experienced and efficient milk salesmen.

Ability to read and write, keep a route book and daily report sheet correctly, understand the instructions given, and appreciate the im-

portance of personal cleanliness are qualifications that should be required. With such qualifications and a good physique as a foundation the possibility of future development into a successful salesman is mainly a problem of organization of the delivery system. A company that does not have a well-formulated standard of service or that neglects to train its route men is more than likely to have just as many different standards of service as it has route men.

The pay of a route salesman must be commensurate with the amount and kind of work required of him. As a general rule the salary of a salesman should compare favorably with the pay of a skilled workman or mechanic. A route salesman who sells 400 quarts daily and makes an effort to build up his route is rendering a service of a higher order than a driver or teamster, and unless he is adequately paid he will eventually seek other employment. The salaries of efficient milk salesmen vary from $25 to $50 per week. A constantly changing personnel of dissatisfied route salesmen precludes efficiency in satisfactory delivery service. The premium or commission system of payment, in which a bonus is offered to salesmen for new customers obtained and for promptness in the collection and return of bottles in addition to basic salary, is the usual method of paying salesmen for efficient service and encouraging them to put forth their best efforts.

Because of the many disagreeable features of route-delivery work there is a tendency among route men to look upon the work as a temporary job until more agreeable employment is obtained. This tendency is often further encouraged by the indifferent attitude of the company toward the route men. Even companies which maintain a most liberal policy toward their salesmen and pay adequate salaries report that only about 50 per cent of their route force can be considered permanent.

Adequate salaries, liberal commissions, and a bonus system of payment. convenient working equipment, and a reasonable amount of time off each month are strong inducements to route salesmen to put forth their best efforts and to continue permanently in delivery work.

Because the net profit on a bottle of milk is usually a small fraction of its selling price, the reduction of credit losses to a minimum is of more importance than in most other lines of business. The advantages and disadvantages of various credit systems, and especially their adaptability to local conditions, should be investigated before any one of them is adopted.

The choice of a cash or credit system, or a modified form of such, will depend upon competitive conditions, prevailing trade practices, and the management of an effective sales organization and distributing system. Reasons for and against may be given for each, but, in general, cash systems have been found to be most economical of op-

eration and losses due to extension of credit are eliminated. The two prevailing systems are: (1) Cash (in advance from retail trade, in which payment for coupon books or tickets is made before the milk is delivered, or on delivery from wholesale trade); and (2) charge accounts, where collections are made weekly, semimonthly, or monthly.

The principal advantages of the cash system are, first, the elimination of uncollectable accounts; second, the elimination of the expense of billing and collecting; third, the reduction of bottle losses. Its disadvantages are the first cost of tickets and the annoyance to patrons in giving the deliveryman the proper tickets at the time of delivery.

The advantages of the charge system are: First, patrons are not inconvenienced by the use of tickets; second, delivery work is facilitated, because the deliveryman is not obliged to collect or check up the tickets; third, it is a convenient method of extending credit. The disadvantages of the charge system are: First, the expense of bookkeeping; second, the loss of bad accounts; third, the higher and more expensive order of salesmanship required on the part of the deliveryman for billing and collcting than in either the cash or cash-in-advance system; fourth, necessity for the service of extra collectors and credit men.

METHODS OF INCREASING SALES.

In new, as well as in old-established plants, it is necessary to be always on the alert for new business. Customers are continually leaving the city or moving to other parts of it and new residents are constantly moving in. Various advertising methods may be employed, the attending success depending upon the care with which they are planned and their timely application. The most effective advertising is of the positive sort or that which emphasizes the healthfulness and food value of milk. Such advertising may be in the form of newspaper articles, billboards, posters, circulars to patrons, and display advertising.

Many milk-distributing plants have offered incentives to their sales force in increasing and extending trade by paying additional commissions or bonuses for new customers, returned bottles, volume of business, collections, or total route sales, as part of the routeman's salary. Some firms employ the policy of consistently extending their business by consolidation with or purchase of the business of competitors. Where the competitor's customers are mostly within territory already covered and can be reached by existing routes, or are in new territory and a nucleus of a route is desired to which other

customers may be added, this method may be profitable, provided the price paid is not exorbitant. Soliciting may be employed where the house-to-house canvassing seems desirable.

COSTS OF MILK DISTRIBUTION.

The costs of milk distribution are dependent upon capital investments in plant and equipment, delivery equipment, and operating expenses both in the plant and in delivery.

Data obtained by careful investigations show that capital investments in plant and equipment range from about $20,000 to $150,000, with an appropriate average of $60,000 for plants handling 2,000 to 5,000 gallons daily. The investment in delivery equipment varies according to the amount of wholesale or retail business and the amount handled on each distributing wagon. It is apparent that when retail wagons cost $200 to $300 each and wholesale wagons $350 to $450 each, and horses $150 to $225 each, and when from 250 to 400 quarts are handled daily on retail wagons and 1,200 to 1,800 quarts on wholesale wagons, the investment on retail wagons may range from $1.25 to $1.75 per quart sold daily and on wholesale wagons from 50 to 75 cents per quart.

Labor costs on retail and wholesale routes vary in different cities and may range on retail routes from 1½ to 2½ cents per quart, with additional costs for horse feed amounting to $1 or more per day or one-fourth to one-third cent per quart. The delivery costs under different local conditions may range from 40 to 65 per cent of the total costs from producer to consumer, which "spread" or margin may range from 4 cents per quart to 6 or 7 cents, and in some instances to 8 cents per quart.

It is impossible to give an average figure which would fairly represent prevailing conditions, for the costs of labor, supplies, and equipment are constantly changing, and conditions are not the same in any two cities. The spread on wholesale sales may vary from 1 to 3 cents less per quart than on retail sales. Thus, with a margin of 3 cents less, and with the assumption that the retail store handles on a 1-cent margin, it is possible for milk to be sold to consumers through stores at 1 to 2 cents less per quart than on retail routes, making house-to-house deliveries.

It should be remembered that under any system of plant operation and sales delivery, costs are largely dependent upon local conditions, the extent to which the business is efficiently managed, and whether detail operations are conducted in an economical manner. Perhaps no one thing is more important for proper management and maintenance of low operating costs than a system of accounts and cost records

which quickly enables the various phases of the business to be analyzed and comparisons to be made, thus giving the best opportunities for policies to be formulated for the greater success of the business.

NECESSITY FOR ADEQUATE ACCOUNTING SYSTEM.

Among the important causes of many business failures in recent years, according to our large commercial reporting agencies, has been a lack of accurate and detailed information concerning the business. Inasmuch as the only reliable source of information concerning business operations is the records kept of them, it would seem that the importance of proper records as an aid to successful management is deserving of more consideration than is ordinarily given the subject. The importance is further emphasized by the statement of a certain national trade association that 85 per cent of the failures in business are due to inadequate bookkeeping. It is the unanimous opinion of those who have made a study of the subject that a very decided improvement must be made in bookkeeping methods before any appreciable decrease can be expected in the present heavy business mortality rate.

In cooperative organizations it is just as essential that adequate and proper accounting records be kept as it is in private and corporate enterprises. Aside from the question of success or failure there are other benefits which may be derived from adequate accounting. Uniformity in the manner in which financial and operating reports are compiled is of great importance. The true progress of a business can be judged only by comparing the results of one year with those of preceding years. Therefore, if it is desired to know the progress that has been made, the reports must be comparable. The reports are not comparable and can not be made so unless the records have been kept on the same bases year by year and all the facts have been recorded. Unless the system is truly adequate, some of these facts are sure to be omitted and thus the entire report rendered worthless.

The preparation of proper income-tax reports, cost statements as a basis for selling prices, wage scales, and the whole operation of the business depend upon information which can be secured only by the use of an adequate system of accounting.

But first it should be determined for a certainty that the system is really adequate. A small number of forms, requiring little work to keep them and purchased at a small initial cost, by no means constitutes an adequate system of accounting. Any system is worthless if it does not supply the information needed to conduct the business properly.

ESSENTIALS OF AN ADEQUATE ACCOUNTING SYSTEM.

The items of information that an adequate system of accounting may furnish are many, but a few of the more important ones will be mentioned.

One important item is the information as to whether the business as a whole has been conducted at a profit or at a loss. This, of course, the books must reveal; but they should reveal much more than the mere fact that a profit or loss has resulted from the operation. They should show which particular part of the operation has been conducted at a profit and which has resulted in a loss. Further, it should be readily seen what particular item of expense or income has had the largest part in accomplishing the result. In order that this may be thoroughly understood, it is necessary to know the exact effect of this item in previous years. This makes it imperative that the statement be prepared on a comparative basis and in a way that will allow each item to be shown side by side with the same item of previous periods.

Another point of information is the balance sheet or statement of the financial condition. This is often thought to be of less importance than the statement of profits. Actually, however, it is of equal if not greater importance, and can reveal an almost untold amount of information when properly prepared and studied. Like the profit-and-loss statement, to be of real value, it must present the financial progress that has been made in addition to the exact financial condition at a certain date. A statement of this kind is fast becoming a necessary part of the information required by many banks in passing upon an application for a loan, and one must be submitted to the Treasury Department as a part of the income-tax report. It should be prepared in the form recommended by the Federal reserve bank, and the accounting system should be so constituted.

In order that two items may be compared, they must be alike. It is impossible to compare items on the financial report at different dates unless they are alike. It means nothing to compare the amount expended for repairs this year with that of last year, unless it is known that exactly the same kind of items have been charged to the open account each year. It is imperative, therefore, that the same ledger accounts be kept in exactly the same manner over a period of years if any reliance is to be placed on the reports. Often it is desirable to compare the results obtained by another organization in the same line of business. This is impossible unless the two organizations use a uniform and standard classification of ledger accounts. These accounts should be so arranged in the ledger that the statement just referred to can almost be prepared

by copying onto a form the balances of the accounts in the order in which they appear in the ledger.

ESSENTIAL RECORDS FOR AN ADEQUATE ACCOUNTING SYSTEM.

The necessary records comprising an adequate system for milk-distributing plants may be classified briefly into:

1. Receiving records.
2. Purchase records.
3. Driver's records.
4. Sales records.
5. Receipts and disbursements records.
6. Accounts receivable records.
7. Pay roll.
8. Storeroom records.
9. The journal and ledger.
10. Statistical records.

The number of forms required for the keeping of these records depends to a large extent upon the volume and complexity of the business. Plants operating in the large cities, receiving their milk supply by rail from receiving stations located at distant points, and operating many routes, milk depots, and retail stores in the city, require a much more detailed system of records and accounts than is required in small plants receiving their milk supply direct from the producers.

As it is not practicable to treat the subject exhaustively in a publication of this nature only the essential information required from each class of records will be described.

THE RECEIVING RECORDS.

The receiving records should show the quantity and value of the milk received, deductions from this amount for any reason, such as advances, and the amount actually paid to each producer, as well as the *total value and quantity of deliveries, deductions, and payments.*

When milk is brought to the plant it should be weighed at the receiving platform and each producer given a receipt for the quantity delivered. The duplicates of these receipts should be sent to the office and entered on milk pay-roll sheets. At the end of the payment period calculation should be made of the quantity delivered by the various producers. The unit price should then be entered and extension made of the gross amount due the various producers. From these amounts deductions should be made for advances or other purposes and the net amount of the check shown. When the day for payment arrives checks should be drawn for the various amounts and their numbers entered in a proper space on the milk pay-roll sheet. The total of these payments should be entered in the check register, the pay roll serving to show the detail necessary for proper reconcilement of the bank account.

PURCHASE RECORDS.

The purchase records should contain a complete history of every purchase (other than milk or cream) made by the organization. These purchase records should include a purchase requisition, a purchase voucher, a voucher register, and a voucher index.

Before any purchase is made a requisition should be issued and approved by the manager or other officer in charge of purchases in order that no unnecessary goods may be bought. This order should be issued in duplicate, the original mailed to the supply firm and the duplicate placed in an unfilled order file until the goods are received. When the invoice is received the duplicate purchase requisition should be removed from the file, attached to the invoice, and returned to the file. When the goods are received the invoice should be taken from the file, checked with the goods and with the duplicate of the purchase requisition, and entered in a purchase voucher. It is often helpful to have a record on the duplicate purchase requisition of the quantity on hand, monthly consumption, and last quotation. A purchase voucher, which forms a filing jacket in which the requisition and invoices are placed for filing, should be filled out and the invoice noted thereon; it is then assigned a number and filed until the end of the month. But one voucher is made for a single concern for any given month; hence a purchase voucher may contain several invoices. Vouchers should be filed in numerical order.

In order that any invoice may be easily located an alphabetical index should be kept on 3 by 5 cards. This index should contain a card for each company from whom purchases have been made at any time. All numbers assigned to purchase vouchers of an individual concern should appear chronologically on the index card showing the company's name.

At the end of the month all purchase vouchers for the month should be taken from file and completed by entering in the space provided the total amount of invoices included in such voucher, and the allocations to the proper ledger account should be made. The vouchers then should be entered consecutively in the voucher register to the credit accounts payable, charges being made as indicated on the voucher, after which these should be filed in numerical order according to the number previously assigned.

The voucher register contains a record of the purchase vouchers. It should be provided with a number of columns, so that items of frequent occurrence may be collected, thus decreasing the amount of work required in posting.

A memorandum column should be provided on the left-hand side for entering the number and amount of checks given in payment as vouchers. No detail accounts payable need be kept, as the voucher and voucher record afford a convenient record of all such items.

DRIVER'S RECORDS.

The product taken out by a driver should be checked out to him on a load sheet by the checker. This load sheet should be retained by the checker until the driver returns, the returned goods and empty containers should be noted thereon, and the net sales determined.

The driver should then fill out a sales report showing the quantity and value of each item sold, the amount of cash and tickets collected, the detail of all other transactions, and should present it, together with his copy of the load sheet, to the cashier as a basis for his daily settlement. In making this settlement the cashier must check the load requisition sheet with the sales report as to quantity of sales, the sales report with the cash turned in as to cash sales and collections, and collect the proper amount from the driver.[1]

The ticket sales should be handled in the same manner as other sales by providing a place for "tickets out" and "tickets in" on the driver's load sheet and for "tickets sold" and "tickets collected" on the driver's sales report. The driver's sales report, after being checked, is passed to the bookkeeper for entry in the sales book. The counter clerk and special delivery driver should be required to make out a daily requisition and sales report.

THE SALES RECORD.

The sales record should furnish a complete detailed analysis of all sales.

A sales sheet should be made out for each salesman and the sales as shown on the sales report entered on this sheet. At the end of the period all sales sheets should be footed and balanced and the several footings recapitulated, giving the total sales for the period. The retail and wholesale sales should be kept separate.

RECEIPTS AND DISBURSEMENTS.

All money should be received by the cashier, who should issue a receipt for each payment, retaining a duplicate in the office. The cash-receipts book is a register of all cash received and must be written up from the duplicates of the cashier's receipts. All money received should be deposited in the bank daily. The cash-receipts book should be so arranged that the receipts can be shown to agree with the bank deposit.

All disbursements should be made by check, which should be entered in the check register. The manager should give the necessary instruction when any payment is to be made. Checks should

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[1] This refers solely to a cash system of sales. In case a credit system is in use, additional safeguards should be established to insure proper accounting for all sales and collections.

be registered when issued and the totals of the check register will be the total disbursements for the period.

ACCOUNTS RECEIVABLE RECORD.

Where a credit business is conducted an abnormally high percentage of loss from bad accounts is frequently experienced. It often happens that a company has credit customers whose names do not appear on the route book, the number of the house being the only record. In allowing credit the driver should never fail to take the customer's name in order that he may be traced in case of moving from one address to another, and his credit standing in the community may be ascertained. Many losses occur through the failure of drivers to follow up collection programs and a neglect of the company to check outstanding accounts properly.

One of the most important features of an accounting system for milk plants is the method used in controlling route charges and collections. Great care should be exercised in checking the receipts on account and the charges shown on the driver's route book and in keeping the amount shown in agreement with the controlling account. Sound business practice demands that milk accounts should not be allowed to stand on the books uncollected for a period of more than 30 days.

PAY ROLL.

A time book or pay roll should be kept at all times, showing for each employee the time worked, rate of pay, and amount due. At the end of the month the total amount due for wages and salary should be charged to the proper expense account and credited to the pay-roll account, whether or not these amounts have been paid.

Checks given in payment for labor or salary and advance payments on them should be charged to the pay-roll account. By following this method expense accounts will always show correct charges regardless of the time of payment, and any credit found in the pay-roll account at the end of the month will represent an accrued liability on account of unpaid wages and salary.

STOREROOM.

Too much emphasis can not be placed on the matter of handling supplies and equipment purchased by a company for sale or for future use. This property should be safeguarded no less carefully than should cash. Frequently this is not done, and the loss occurring through this neglect is a serious factor in the failure which often follows. Therefore, a very thorough system of accounting for supplies placed in and withdrawn from the storeroom should be kept.

All supplies purchased for future use should be kept in the storeroom and charged to the storeroom account. These supplies should be recorded on an inventory sheet. As supplies are required for use a storeroom requisition should be made by the employee needing these supplies, such requisition showing the quantity, size, and other information necessary to identify the supplies desired. The requisition must be approved by the factory foreman or manager and presented to the storeroom keeper, who will deliver the material to the employee. The storekeeper should then fill in the price and at intervals record the requisitions on the inventory sheet. At the end of the month the value of the material withdrawn from the storeroom is credited to storeroom accounts and charged to the various accounts affected by the use of this material.

THE JOURNAL.

All the information recorded in the records heretofore described is classified monthly and made ready for posting into the general ledger in a book called the journal. This book is all-important, and is a connecting link between the original record and the ledger from which all information is secured to compile financial and operating reports. All general ledger posting must be made from this book (the journal) and from no other records.[2]

THE GENERAL LEDGER.

The ledger is the book of accounts. After the transactions of the business have been recorded in the journal, the debit and credit items arising from such transactions are posted (or transferred) to the proper accounts in the ledger. In this manner all the facts concerning the particular subject are collected under its name and can be viewed as a whole.

Any system of accounting, to be of maximum value to those who control the business, must have a very carefully planned and clearly defined classification of ledger accounts, and the person charged with keeping these accounts must adhere rigorously to this classification.

THE STATISTICAL REPORTS.

Inasmuch as the entire bookkeeping is carried on for the purpose of accumulating and presenting information concerning the operation of the business, too much care and attention can not be given to the preparation of statistical reports, chief among which are the income and expense statements, and the balance sheets, and the cost sheets.

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[2] In large and well-organized milk-distributing plants it is equally satisfactory to make postings direct from the original records; in the average milk plant, however, this is not advisable.

The income and expense statements should show in detail just which phases of the business are most profitable, the net profit or loss, and all the facts relative to the operation of the business for the period, as well as comparison with the previous period. The balance sheet should reflect the exact financial condition and should also show comparison with previous periods. The cost reports must show the unit cost (per quart) of every item of expense and the total cost per unit.

QUANTITY RECORDS.

Among the most important of all are the records of the quantity of milk handled through the various processes. Large volume (or quantity) is an important factor in a milk-distributing business, and for this reason unit costs must be closely watched. No manager can form a correct judgment of the efficiency of the operations unless he has the total quantity to compare with the total cost, and an accounting system arranged to show such information will be the best possible tool with which to ward off business failure.

It would be impossible to put too much emphasis on the importance of keeping adequate quantity records.

COST OF KEEPING ADEQUATE RECORDS.

A word of warning might be spoken regarding the operation of an accounting system. It is often looked upon as a necessary evil, the expense of which should be reduced in every way possible, and especially by such methods as the employment of low-salaried, incompetent bookkeepers, whose only recommendation is too often the small salaries for which their services may be secured. Unquestionably bookkeeping and all office expense should be kept as low as possible, but any reduction which tends to confuse and distort the information which a properly operated accounting system can furnish for the guidance of the management should not be considered for a moment. Without these important reports, those responsible for the direction of the affairs of the organization have no information on which to formulate the policies of management. Under these conditions proper guidance of the business is an impossibility.

A first-class bookkeeper will prove an exceedingly valuable asset; and after his work is done, to reap the best benefits possible from an adequate accounting system, nothing can take the place of a regular independent audit by a reputable firm of public accountants. The cost may seem excessive, but it will not be when compared with the benefits derived from it.

APPENDIX.

BY-LAWS OF THE ——— ——— ASSOCIATION.[1]

ARTICLE I.—*Name.*

SECTION 1. This association, incorporated under the laws of the State of ——— ———, shall be known as the (——— ——— Association).

SEC. 2. Its principal office shall be located in the town of ——— ———.

ARTICLE II.—*Objects.*

SECTION 1. The objects of this association shall be to encourage better and more economical methods of production, manufacture, and sale of milk, cream, butter, cheese, and other dairy products and dairy by-products and to engage in handling, grading, marketing, standardizing, manufacturing, storing, and advertising dairy products and dairy by-products.

SEC. 2. In order to carry out these objects the association shall have power—

(*a*) To purchase, rent, buy, build, or otherwise acquire and own, sell, lease, or control such buildings and equipment and real and personal property as may be needed for the convenient conduct of its operations.

(*b*) To borrow money and to secure the same by a mortgage, deed of trust, or other form of security upon any of its property, real or personal.

(*c*) To cooperate and affiliate, through membership or otherwise, with any other cooperative association formed for similar purposes in order to carry out the objects of this association.

> NOTE.—Make the objects as definite as possible; but it is also well to make them sufficiently broad in scope to cover any future efforts of the association. Care should be taken to state the objects, so as to keep the activities within the limits of the power conferred by the statute under which the association is incorporated, as well as in harmony with the articles of association.

ARTICLE III.—*Membership.*[2]

SECTION 1. Any bona fide producer of dairy products in the territory served by this association may become a member of the association by agreeing to comply with the by-laws of this organization and purchasing at least (one) share of capital stock.

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[1] Adapted from Bulletin No. 541 of the U. S. Department of Agriculture entitled Cooperative Organization By-Laws. All matter appearing in parenthesis is suggestive merely and is to be altered to suit the best interest of each association. Those who desire to form an association which will come within the scope of the Capper-Volstead Act should remember that such an association (*a*) must be composed entirely of producers; (*b*) must not deal in the products of nonmembers to an amount greater in value than such as are handled by it for members; and (*c*) must comply with one or both of the following requirements: (1) That no member of the association is allowed more than one vote because of the amount of stock or membership capital he may own therein, or (2) that the association does not pay dividends on stock or membership capital in excess of 8 per centum per annum. Fuller information concerning the Capper-Volstead Act may be obtained from the Bureau of Agricultural Economics, United States Department of Agriculture.

[2] The following is applicable to capital-stock organization. On p. 43 suitable sections for nonstock organizations are suggested.

ARTICLE IV.—*Fiscal Year—Meetings.*

SECTION 1. The fiscal year of the association shall commence (January 1) and end on (the 31st of the following December).

SEC. 2. The annual meeting of the association shall be held in the town of (————————) on the (third Monday in January) of each year, at (10 o'clock a. m.)

> NOTE.—The annual meeting should be held as soon after the end of the fiscal year as will allow for the settlement of all accounts, auditing of the books, and the preparation of the annual reports of the officers.

SEC. 3. Special meetings may be called at any time by the president. He shall call such meetings whenever (10 per cent) of the members shall so request in writing.

SEC. 4. Notice of the annual meeting shall be mailed by the secretary to each member at least 10 days previous to the date of the meeting and such notice shall be published in a local newspaper not less than (10 days) previous to the date of the meeting. At least (10 days) before the date of any special meeting the secretary shall mail notice of such meeting to each member, which shall state the nature of the business to be transacted at such meeting.

ARTICLE V.—*Quorum.*

SECTION 1. (One-fourth) of the members in good standing shall constitute a quorum for the transaction of business at any meeting.

> NOTE.—When the organization is small and compact, the proportion required for a quorum may be larger than in a large organization which includes considerable territory.

ARTICLE VI.—*Directors and Officers.*

SECTION 1. The board of directors of this association shall consist of (seven) members. After the adoption of these by-laws, the members shall elect from among themselves (seven) directors, who shall hold office for the period of one year or until their successors shall have been elected and qualified and shall enter upon the discharge of their duties.

> NOTE.—In some States the corporation laws stipulate the number of directors and officers an association shall have. The plan of having each district represented on the board of directors tends to avoid jealousies between the various districts, but a small board of capable men is to be preferred to a large board composed largely of members who can not give proper attention or time to their duties on the board. In case it should be the wish of the members to recall a director this can be effected under section 6 of this article.

SEC. 2. The board of directors shall meet within (10) days after the first election and after each annual election, and shall select by ballot a president and a vice president from among themselves, and a secretary treasurer (or a secretary and a treasurer) who may or may not be a member of the association. The officers shall hold office for one year or until their successors are duly elected and qualified.

> NOTE.—In some organizations it is desirable to have some one outside the membership act as secretary or treasurer. When such is desired proper provision for it should be made in the by-laws. In some cases, especially when the board of directors is large, it is desirable to have an executive committee. Such a committee may consist of the officers and one or more members of the board of directors.

SEC. 3. Any vacancy in the board of directors shall be filled for the unexpired term at a special meeting called for the purpose.

Sec. 4. (Four) members of the board of directors shall constitute a quorum at any meeting of the board.

Sec. 5. (The compensation, if any, of the board of directors and the officers shall be determined by the members of the association at a regular or called meeting of the association.)

Sec. 6. Any director or officer of the association may be removed from office at any annual or special meeting by a two-thirds vote of the members present following the mailing of a notice to each member in accordance with these by-laws specifying that the matter of the removal of such director or officer is to be voted upon at such meeting. Such director or officer shall be informed in writing of the charges against him at least (10) days before such meeting, and at such meeting shall have an opportunity to be heard in person, by counsel, and by witnesses.

Article VII.—*Duties of the Directors.*

Section 1. The board of directors shall be responsible for the proper conduct of the business affairs of the association and shall make any necessary rules and regulations, not inconsistent with law or with these by-laws, for the management of the business and the guidance of the officers, employees, and agents of the association.

Sec. 2. The board of directors shall have the power to establish rules and regulations regarding the inspection and grading of the products handled by the association.

Sec. 3. All brands, labels, trade-marks, and the like, established by the association, shall be registered and become its property, and they shall be attached only to such grades as shall be designated by the board of directors.[3]

Sec. 4. The board of directors may employ a business manager, fix his compensation, and dismiss him for cause. He shall conduct the business of the association in accordance with a policy agreed upon and approved by the board of directors.

Sec. 5. The board of directors shall require the treasurer and all other officers, agents, and employees responsible for the custody of its funds or property to give bond with sufficient surety for the faithful performance of their official duties, the cost of which shall be paid by the association.

Sec. 6. The board of directors shall meet on the (first Saturday) of each month at the office of the association in the town of (———— ————). Special meetings of the board shall be held upon call of the president or upon written request of (three) members of the board.

Article VIII.—*Duties of the Officers.*

Section 1. The president shall—

(*a*) Preside over all meetings of the association and of the board of directors.

(*b*) Sign as president, with the (secretary-treasurer) all checks, notes, deeds, and other instruments on behalf of the association.

(*c*) Call special meetings of the association and of the board of directors and perform all acts and duties usually required of an executive and presiding officer.

Sec. 2. In the absence or disability of the president, the vice president shall perform the duties of the president.

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[3] The rules for grading and inspection will necessarily depend on the organization and the kind of business engaged in and this should be kept in mind when drawing up the by-laws.

SEC. 3. The (secretary-treasurer) shall—

(*a*) Keep a complete record of all meetings of the association and of the board of directors.

(*b*) Sign as (secretary-treasurer), with the president, all checks, notes, deeds, and other instruments on behalf of the association, previously approved by the business manager.

(*c*) Serve all notices required by law and by these by-laws.

(*d*) Receive and disburse all funds and be the custodian of all property of this association.

(*e*) Keep a complete record of all business of the association and make a full report of all matters and business pertaining to his office to the board of directors monthly and to the members at their annual meeting and make all reports required by law.

(*f*) Perform such other duties as may be required of him by the business manager, the board of directors, and the association.

> NOTE.—When the offices of secretary and treasurer are separate the duties of each should be given in different sections.

ARTICLE IX.—*Duties and Powers of the Business Manager.*

SECTION 1. Under the direction of the board of directors, the business manager shall employ and discharge all employees, agents, and laborers. He shall generally supervise the production, handling, manufacture, and marketing of the dairy products and dairy by-products of the association, to the end that the business of the association may be conducted in the most economical and efficient manner.

> NOTE.—The manager occupies a highly important position and his power must be limited as little as possible. The success or failure of the association rests to a large degree with him. He can not be held responsible if he is to be dictated to at will by each member or if the officers are to meddle constantly with his work. This does not mean that the manager should not be subject to the orders of the board of directors. He should take suggestions from the officers and members and from them and his own experience formulate a business plan. Whenever a manager loses the confidence of the members he should be replaced.

ARTICLE X.—*Capital Stock.*[4]

SEC. 1. The capital stock of this association shall be ——— dollars, divided into ——— shares of ——— dollars each.

SEC. 2. Each member shall subscribe for one share of capital stock for each ——— of ——— to be delivered by him to the association. Such shares shall be paid for in cash, or deductions may be made and applied to the payment of the shares from amounts due him by the association for products delivered and sold by it. The amount of such deductions shall be fixed by the board of directors. Shares shall not be issued until paid for in full.

SEC. 3. Whenever any stockholder desires to sell his stock he shall first offer it to the association for purchase by it or by a person or persons designated by the board of directors of the association at a price to be conclusively determined by the board of directors. In the event the stock is not purchased by the association or by a person or persons designated as aforesaid, within 30 days after the receipt of a written notice by the association offering the stock for sale, then the stockholder may sell the stock to any person engaged in the production of dairy products. This restriction on the transfer of stock shall be printed on every certificate of stock.

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[4] These sections are applicable to capital-stock organizations. On p. 43 suitable sections for nonstock organizations are suggested.

Sec. 4. If any member shall by purchase or by operation of law come into possession of more than ——— shares of the capital stock of this association, the board of directors may elect to purchase, and such member shall then sell to the association, such excess shares at a price to be conclusively determined by the board of directors, plus any dividends or refunds due and unpaid. Also, in the event of the death or disability of the owner of any shares of stock in this association, such shares of stock may be purchased by the association and shall, in the event the board of directors elects to purchase them, be sold by such owner or his legal representatives to the association at a price to be conclusively determined by the board of directors, plus any dividends or refunds due and unpaid.

> Note.—The legal effect of sections 2, 3, and 4, above, depend entirely upon the charter provisions and the laws of the State in which the association is incorporated. They are suggested here as possible means of safeguarding cooperative principles, and are to be incorporated into or excluded from the by-laws upon the advice of competent legal counsel. Printing these restrictions upon the body of the stock certificate is a convenient and effective method of giving notice of such restrictions to intending purchasers.
>
> If the organization desires to have both common and preferred stock, proper provision for such should be made in this article.

Article XI.—*Contracts and Agreements.*

Section 1. Every producer delivering milk or dairy products to this association shall enter into a contract with the association in the form required by the board of directors, containing, among others, the following provisions:

(*a*) That the member, by said contract, appoints the (——— ——— Association) his sales agent to sell all dairy products and dairy by-products produced by him for sale or such part thereof as shall be specified in the contract, and binds himself to deliver such products to the (——— ——— Association) for sale at such time and place as the association directs.

(*b*) That said contract shall run continuously unless canceled by the member on the ——— of any year by surrendering his contract and giving written notice to the association at least 30 days prior to said date of his desire to cancel the contract. Such cancellation shall be subject to any indebtedness due from the member to the association.

> Note.—No cooperative association should attempt to do business without first having made a definite contract with each producer. Such contracts tend to give stability and permanence to the organization and enable the manger to plan more definitely for the handling and sale of the products received.

Article XII.—*Duties and Rights of Members.*

Section 1. A member shall have the right to give away or retain for his use in his household or on his farm such of his dairy products as he may wish, but he shall not sell any products contracted to the association to an outside party, except products offered to and rejected by the association.

Sec. 2. In case any member is offered a price in excess of the price obtainable by the association, said member shall refer said bid to the association.

Sec. 3. On or before ——— day of ——— of each year each milk producer shall report to the association the number of cows which he has in his herd and the approximate amount of dairy products which he expects to market monthly through the association during the ensuing year.

Sec. 4. Each stockholder of the association shall have only one vote. Voting by proxy shall not be permitted. Members may vote by mail on specific ques-

tions in those instances where authorized to do so by the board of directors. In such cases the secretary shall mail notices of such specific questions to each member (10) days before the date of the meeting. Members voting by mail on specific questions shall transmit their ballots to the secretary of the association by registered mail and such ballots shall be counted only in the meeting at the time at which such vote is taken.

NOTE.—In a stock company, organized to earn profits on the money invested in the business, voting rights are granted to the stockholders in proportion to the number of shares held. In a cooperative association where the individual members have common interests, equality is obtained by limiting each member to one vote. The practice of allowing members to collect the proxies of absent members and vote the same tends to give such members undue influence in the affairs of the association.

SEC. 5. Any member having a grievance or complaint against the association may appeal to the board of directors, or to the members, at any regular or called meeting.

ARTICLE XIII.—*Expenses and Payments.*

SECTION 1. The expenses of operating and maintaining this association shall be met by a percentage deduction from the returns for products sold, the amount of such percentage to be fixed by the board of directors.

SEC. 2. The returns from the sale of all products of the same grade shall be pooled and final payments made to producers on the basis of the average price received during such periods as the board of directors from time to time may determine. Advance or partial payments for such products shall be made to the producers as the board of directors may determine.

ARTICLE XIV.—*Refunds and Damages.*[5]

SECTION 1. After payment to the producers of a specified portion of the amount received for their product, and after the season's expenses are paid and a suitable sum, to be determined by the board of directors, set aside for depreciation and reserves, the balance shall be divided as follows:

(*a*) The stockholders shall receive not to exceed (6) per cent per annum on the par value of their stock.

(*b*) The remainder, if any, shall be divided among the patrons of the association in proportion to the value of the products handled for all such patrons whether members or nonmembers.

SEC. 2. Any member who fails to live up to his agreement or fails or refuses to deliver his products to the association for sale in accordance with said agreement shall pay to the association as liquidated damages the sum of ——— for each ——— of ——— not delivered by him to compensate the association for the loss sustained by the breach, and to enable it to meet and equitably distribute overhead and maintenance expenses involved in the operation of the association and in providing and maintaining facilities for the handling and marketing of the products of its members; said sum may be deducted from any money due the member in the possession of the association.

ARTICLE XV.—*Accounts and Auditing.*

SECTION 1. This association shall install a standard system of accounts, and provide such accounting appurtenances as may be necessary to conduct the business in a safe and orderly manner.

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[5] These sections are applicable to capital-stock organizations. On p. 43 suitable sections for nonstock organizations are suggested.

SEC. 2. The books and records of the business of the association shall be audited (monthly) by a competent auditor selected by the board of directors. A complete annual audit shall be made by a competent accountant previous to the date of each annual meeting, at which meeting the report of the auditor shall be presented in full. Special audits shall be made upon order of the board of directors or upon a majority vote of the members present at any regular or called meeting.

ARTICLE XVI.—*Amendments.*

SECTION. 1. These by-laws may be amended at any meeting by two-thirds vote of the members present in person or voting by registered mail, provided that notice of such proposed amendment is included in the call for said meeting.

BY-LAWS FOR NONSTOCK ORGANIZATIONS.

While most of the cooperative milk plant organizations have been formed with capital stock, the nonstock plan has been adopted in some instances. The following articles are suggested for substitution for the corresponding articles in the preceding by-laws in adapting them to organizations formed without capital stock.

ARTICLE III—*Membership.*

SECTION 1. Any bona fide producer of dairy products in the territory served by this association may become a member of the association by agreeing to comply with the requirements of these by-laws.

SEC. 2. Upon the payment of the membership fee, the association shall issue a certificate of membership to the applicant. Such certificate of membership shall not be transferable. The willful violation of the by-laws of this association or of the contract or contracts entered into by the association with any member shall constitute a sufficient cause for expulsion of such member.

SEC. 3. No member shall be expelled from the association except by a two-thirds vote of the members present at any annual or special meeting following the mailing of a notice to each member in accordance with these by-laws, specifying that the matter of the expulsion of such member is to be voted on at the meeting. The member shall have charges preferred against him 10 days in advance of such meeting and shall have an opportunity to be heard in person, by counsel, and by witnesses. After a hearing, if the board of directors determines that a member has ceased to be a bona fide producer of dairy products, his membership shall be terminated and his membership certificate canceled.

ARTICLE X.—*Membership Fees and Finance.*

SECTION 1. Each member shall pay in advance to the association a membership fee of ($———).

SEC. 2. Certificate of indebtedness which shall draw interest at the rate of (6) per cent per annum, may be issued by the board of directors to provide capital to be used for the purchase or construction of buildings, the lease or purchase of lands, the purchase of equipment, and for other purposes.

SEC. 3. These certificates shall be issued in series and shall be retired by a special fund created by levying a percentage assessment, to be determined by the board of directors, on the products sold through the association. This amount shall be sufficient to retire all certificates as they fall due and pay the interest thereon.

SEC. 4. At the end of each fiscal year each member shall receive a certificate for the amount of money which he has contributed that year to the special loan fund levied on his products. These assessments shall continue from year to year, and out of the proceeds arising therefrom the holders of certificates shall be paid the amounts due them, and this process of repayment shall continue during the life of the association.

ARTICLE XIV.—*Refunds and Damages.*

SECTION 1. After the season's expenses are paid and a suitable sum, to be determined by the board of directors, set aside for depreciation and reserves, the balance of the season's returns of savings on products shall be divided among members and nonmember patrons, if any, in proportion to the value of their products sold or handled by the association for them.

SEC. 2. Any member who fails to live up to his agreement, or fails or refuses to deliver his products to the association for sale in accordance with said agreement shall pay to the association as liquidated damages the sum of ——— for each ——— of ——— not delivered by him to compensate the association for the loss sustained by the breach and to enable it to meet and equitably distribute overhead and maintenance expenses involved in the operation of the association and in providing and maintaining facilities for the handling and marketing of the products of its members; said sum may be deducted from any money due the member in the possession of the association.

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BY-PRODUCTS FROM CRUSHING PEANUTS.

By J. B. REED,[1] *Assistant Chemist, Cattle Food Laboratory, Miscellaneous Division, Bureau of Chemistry.*

CONTENTS.

PEANUT-CRUSHING INDUSTRY.

The popular idea seems to be that the peanut is marketed chiefly in the roasted form. As a matter of fact, however, these nuts are used principally in making salted peanuts, peanut butter, and confectioners' and bakers' goods, and in the manufacture of oil and meal. The peanut industry was of little commercial prominence until 1870, when it began to grow gradually. By 1900 the quantities of peanuts raised were increasing rapidly, and since 1915, when the crushing of peanuts for oil and meal was undertaken on a commercial scale, the growth of the peanut-crushing industry has been phenomenal. This growth may be attributed to the fact that the peanut can to a large extent take the place of cotton as a cash crop in regions seriously infested with boll weevil. Short cotton crops have placed the planters and oil millers in large cotton-producing areas in an extremely difficult position. The planters suffered from being deprived of a cash crop and the oil millers suffered from having heavy investments in oil mills for which there seemed to be no further use. The utilization of the peanut for making oil and meal gave the planters a new cash crop and enabled the millers to continue their operations.

[1] Acknowledgment is made to G. P. Walton and L. E. Bopst, of the Cattle Food Laboratory, for assistance in the analytical work.

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CRUSHING PEANUTS.

VARIETIES USED.[2]

The Spanish variety is the one grown principally for the production of oil. The meats of this variety have a higher oil content than those of any other, with the possible exception of the Valencia, or Tennessee red. It has a higher proportion of meats to hulls than any other variety and is adapted to a wider range of soil and climatic conditions.

PROCESSES.

Most of the crushing of peanuts is done in cottonseed-oil mills, which are well adapted to this work. These mills run for part of the season on cotton seed, when it is available, and for another part of the season on peanuts. Thus a close relationship exists between the cottonseed-oil industry and the peanut-oil industry, although many mills crush peanuts exclusively.

The processes for crushing peanuts in this country are of two distinct types—the hydraulic, which is intermittent, and the expeller, which is continuous.

HYDRAULIC PROCESS.

From the storehouses to which they are brought by the farmers the peanuts are run through shakers or conveyors having fine sieves, to remove the sand and fine dirt, and then through larger sieves, consisting of perforated plates having holes large enough to permit the peanuts to drop through, thus separating them from the sticks, vines, stones, and larger pieces of trash, which pass out from the tail of the machine.

The peanuts are next taken in screw conveyors to the huller. Sometimes this is an ordinary cottonseed bar huller, or a slight modification of it, consisting of a cylinder the lower part of which is made of sharp-edged steel bars, with revolving sharp-edged bars attached to a frame within. The peanuts are chopped as they pass between the sharp edges, and the meats and hulls pass out through slits between the bars. Most mills, however, use the so-called disk huller. This consists of a cylinder the lower half of which is made of steel bars properly spaced, having inside rough-faced disks, some revolving and others stationary, placed side by side, so that the revolving disks alternate with the stationary disks. Peanuts are fed in at the top, the hulls are rubbed off as they pass between the disks, and the hulls and meats pass out through the slits between the bars below.

The stock is next conveyed to a shaker machine, where the meats are separated from the hulls by means of sieves and an adapter

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[2] A complete description of the varieties of peanuts grown in the United States is given in Farmers' Bulletin 751, copies of which may be had on application to the Division of Publications, U. S. Department of Agriculture, Washington, D. C.

attached to the air-suction pipe which sucks the hulls away from the meats. This adapter, which is funnel-shaped and flattened out to a slit about 2 inches wide, extends from one side to the other of the shaker over which the mixture of meats and hulls is passing. In some mills only one adapter is used; in others several adapters are placed side by side. By varying the speed of the fans and making other adjustments, it is possible to separate practically all the hulls from the meats or retain any desired amount. In the past the practice has been to leave 10 or 15 per cent of the hulls in the meats for the purpose of securing a satisfactory extraction. It has been found, however, that this is not necessary for a successful extraction. In fact, the presence of the hulls prevents efficient extraction, for the reason that they soak up oil like a sponge. Most up-to-date mills now remove all hulls possible from the meats before crushing.

After the hulls have been removed the meats pass through rolls, which crush them. In some cases the rolls that are employed in crushing cotton seed are used, but usually they are modified by having some of the smooth rolls replaced by corrugated rolls. The object of crushing is to open the oil cells as much as possible, thus securing a more efficient extraction.

From the rolls the crushed meats go to the cooker, where they are tempered and cooked for the purpose of further breaking up the oil cells.

From the cooker the material goes to the cake formers, where it is made into cakes inclosed in hair cloth. The cakes are then placed in the hydraulic presses and subjected to great pressure, which presses out most of the oil, leaving a cake containing from 6 to 8 per cent of oil. This cake is ground into meal. Usually some of the hulls previously removed are ground back with it, to give meal containing the desired amount of protein.[3] The idea seems to be to produce meal corresponding in protein content to the various grades of cottonseed meal.

EXPELLER PROCESS.

In the expeller process the peanuts are not subjected to cooking, but are chopped and heated to some extent in a steam-heated conveyor which carries the material to the expeller. Usually the hulls are not removed, so that often the cake contains all the hulls. Some mills, however, shell the peanuts and crush them, thus securing an excellent virgin oil that needs no refining, but is merely filter-pressed. The cake obtained in this way makes a meal having an exceptionally high protein content and is the source of peanut flour.

[3] Hulls are either left in cottonseed meal or are ground back in, to give a cottonseed meal of desired protein content.

SHELLING PLANTS.

Many mills run shelling plants in which the best nuts are separated to be marketed as shelled peanuts. The seconds are either pressed out separately or run in with the regular stock when the mill is running on stock peanuts in the usual way. The principle of the sheller is the same as that of the disk huller (p. 2), but in addition it has attached to it screens, shakers, and fans, so that the meats come out almost entirely separated from the hulls. The machine is run to make as many of the meats as possible come out whole.

PRODUCTS OBTAINED FROM CRUSHING PEANUTS.

Some mills make feeds by grinding the peanut cake with peanut hulls, hay, cottonseed meal, cottonseed hulls, etc., with the idea of utilizing the hulls, which have a very low feeding value. It may be possible to use the hulls in this way if the product is not to be shipped very far, but their shipment for any great distance is not economical.

Meals containing from 45 to 50 per cent of protein are produced but seldom placed on the market. Meals containing all the hulls, with a protein content of from 34 to 38 per cent, and meals containing an excess of hulls obtained from shelling plants or some other source are also found. Between these extremes are several grades.

Some mills run almost entirely on seconds, which they buy from shelling plants, and on the germ (known to the trade as the heart) and skins, which they obtain from peanut-butter mills and peanut-confection establishments. A low-grade oil and a low-grade meal are thus obtained. Although peanut skins do not contain much oil originally, those from peanut-butter mills are high in oil, which is tried out from the meats and absorbed by the skins during the roasting. Such skins contain from 20 to 30 per cent of oil. Products obtained by crushing skins, germs, low-grade meats, etc., should not be designated as peanut meal; they should be labeled to show their true character.

Fertilizers are among the valuable products obtained from the crushing of peanuts. Peanut cake, however, is too valuable as a feed to be used directly as a fertilizer. The ideal thing would be to feed all the peanut meal produced to animals, using the resulting manure for fertilizer. Unfortunately, it is not always possible to do this. For business reasons a great deal of peanut meal is sold to the planters, who use it directly for fertilizing purposes. Often it seems advisable for the oil millers to buy the peanuts from the planters, giving them the peanut meal as part payment. The planter brings in a load of peanuts and takes away a load of meal. In this way the working capital of the mill is reduced materially, while the

farmer saves on his transportation of fertilizer. Although, from a broad economic standpoint, it is not good practice to use either cottonseed meal or peanut meal directly as a fertilizer, this practice probably will be continued on account of local conditions.

The unusual value of peanut meal as a feed for animals, which is not generally recognized, has been reported by C. O. Johns and D. Breese Jones,[4] who have brought out the important fact that the proteins in this product are high in lysine.

Osborne and Mendel and other workers have shown that lysine is essential to the growth of animals. Nutrition experiments indicate that the animal organism can not synthesize lysine, which must, therefore, be provided in suitable quantity in the food to insure normal growth. Since the muscle substance of animals contains about 7 per cent of lysine, foods deficient in this essential amino-acid should be supplemented by the addition of other foods which contain a high percentage of lysine. Wheat and corn, both of which contain but little lysine, should therefore prove more efficient diets if supplemented by some food of high lysine content. Peanut meal appears to be well adapted to this purpose. From a nutritive standpoint, it is one of our cheapest foods and seems to possess no objectionable properties. Animals fed on it thrive and increase rapidly in weight. It therefore seems probable that corn and wheat could be much better utilized and a considerable saving in the cost of feeding effected by supplementing these cereals with peanut meal.

Many samples of products obtained during the crushing of peanuts for oil were analyzed. Most of the peanuts used for this purpose were of the Spanish variety; a few mixtures of the Virginia Runner and Spanish were analyzed. The results of the analyses are reported in Tables 1 to 11.

TABLE 1.—*Pure peanut meals and cake from crushing shelled hand-picked peanut meats.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
31243	7.5	4.0	8.6	50.6	4.7	24.6
31244	7.5	4.4	8.4	52.1	5.0	22.6
29297	6.5	4.4	8.0	52.3	4.5	24.3
Average	7.2	4.3	8.4	51.7	4.7	23.8

TABLE 2.—*Products from crushing whole peanuts by the expeller process.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
29252	6.1	3.9	6.5	34.4	27.1	22.0
29253	5.8	4.3	6.6	36.8	25.8	20.7
29295	6.4	3.6	7.2	34.7	26.4	21.7
31281	7.2	4.1	6.4	37.7	22.2	22.4
31282	5.1	4.3	10.1	37.6	22.3	20.6
31294	6.6	3.9	7.2	38.6	21.9	21.8
Average	6.2	4.0	7.3	36.6	24.3	21.5

[4] The proteins of the peanut, *Arachis hypogæa:* II. Distribution of the basic nitrogen in the globulins arachin and conarachin. J. Biol. Chem. (1917), **30**: 33–38.

TABLE 3.—*Pure peanut hulls from hand-shelled peanuts.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
31400	8.7	2.1	1.2	6.1	67.9	14.0
31401	8.0	3.1	.8	5.7	64.5	17.9
31409	7.5	2.6	.6	5.6	65.3	18.4
31249	6.7	2.2	1.6	5.8	69.7	14.0
31280	6.5	2.4	1.0	5.2	68.4	16.5
31292	8.3	2.5	.8	4.4	70.0	14.0
31302	6.2	2.0	.5	5.0	69.3	17.0
31304	8.3	2.5	1.6	5.9	66.3	15.4
31310	7.7	3.2	1.9	5.9	65.6	15.7
31317	6.9	2.6	.6	4.6	68.9	16.4
31318	6.0	2.9	.7	5.0	68.8	16.6
31328	8.6	2.7	.6	4.8	68.6	14.7
31330	7.5	2.1	.9	5.5	63.5	20.5
Average	7.5	2.5	1.0	5.4	67.5	16.1

TABLE 4.—*Peanut hulls obtained at the mills.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
31255	7.1	2.4	1.4	5.6	70.0	13.5
31290	8.1	2.8	2.7	6.8	61.6	18.0
31293	8.2	4.8	2.7	6.1	64.0	14.2
31301	8.6	3.7	2.2	6.3	61.4	17.8
31302	6.2	1.2	.5	5.1	69.3	17.7
29262	7.8	2.9	6.5	7.2	61.2	14.4
29257	8.5	2.9	.4	4.4	69.6	14.2
29225	8.3	2.6	.4	6.1	64.6	18.0
29263	7.9	1.9	.5	5.0	71.3	13.4
29336	7.8	4.6	4.1	9.8	47.0	26.7
29337	7.4	3.6	3.6	9.6	50.7	25.1
31245	8.1	2.1	3.3	7.5	62.3	16.7
31306	8.2	3.3	1.9	6.9	65.5	14.2
31316	8.2	4.0	9.1	10.1	51.2	17.4
31319	8.6	2.7	7.8	5.6	61.0	14.3
31326	8.5	2.7	1.2	5.4	66.7	15.5
31411	6.6	2.8	2.2	8.1	62.3	18.0
31801	8.6	3.7	2.2	6.3	61.4	17.8
Average	7.9	3.0	2.9	6.8	62.3	17.1

TABLE 5.—*High-grade cake and meal made by the hydraulic process from stock from which hulls had been removed by suction.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
29261	7.7	5.9	7.5	46.6	8.8	23.5
31251	6.4	7.0	8.1	45.9	10.5	22.1
31252	6.3	7.3	8.0	45.3	11.1	22.0
31256	7.8	5.0	7.7	46.5	10.5	22.5
31257	7.4	5.3	9.7	47.2	8.8	21.6
31288	7.4	4.0	7.1	46.3	10.2	25.0
31289	8.0	4.5	7.8	45.8	11.2	22.7
31286	6.9	4.6	10.5	48.3	8.1	21.6
31307	6.7	5.1	10.2	47.1	9.5	21.4
31309	7.9	4.7	8.5	47.6	9.3	22.0
31312	6.9	5.9	8.1	49.0	7.4	22.7
31314	7.1	5.3	9.4	48.0	8.5	21.7
31315	7.9	9.6	6.9	46.5	4.6	24.5
31321	7.6	5.4	8.0	45.9	10.8	22.3
31327	7.9	5.5	9.8	46.9	9.2	20.7
31410	7.5	4.6	8.3	47.1	9.6	22.9
Average	7.3	5.6	8.5	46.9	9.5	22.4

TABLE 6.—*Peanut meals and cake of lower grade with different quantities of hulls left in or ground in after pressing.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
29224	7.1	4.5	8.1	39.5	19.6	21.2
29226	6.8	4.5	8.4	38.6	21.2	20.5
29242	6.8	5.2	9.2	31.9	27.2	19.7
29247	6.4	4.9	7.6	38.4	19.8	22.9
29248	6.8	5.5	8.2	39.5	16.7	23.3
29260	7.6	5.6	6.4	40.9	14.2	25.3
29339	7.3	8.1	8.7	38.8	16.0	21.1
31238	7.8	4.3	8.8	43.3	11.7	24.1
31242	8.5	3.2	5.5	28.4	34.9	19.5
31291	8.0	4.4	6.8	43.8	15.2	21.8
31300	7.4	3.7	11.4	34.4	21.5	21.6
31303	7.5	3.8	10.9	34.8	26.5	16.5
31311	7.2	5.8	7.0	36.7	24.0	19.3
31325	7.8	4.3	8.8	44.4	12.9	21.8
31399	8.3	2.7	8.8	43.4	12.1	24.7

TABLE 7.—*Peanut stock from which the hulls had been removed by suction on the way to the crushers.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.	Hulls not removed.[1]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
31250	4.4	2.8	45.7	28.7	3.5	14.9	2.0
31287	4.0	2.7	40.1	28.8	10.6	13.8	[2] 12.0
31294	6.9	2.8	46.1	29.8	3.5	10.9	2.5
31308	4.6	3.0	42.8	28.2	8.4	13.0	5.0
31313	5.3	2.4	48.0	27.6	4.0	12.7	3.5
31320	4.3	2.6	48.1	29.1	2.8	13.1	1.0
31324	5.0	2.5	47.9	30.2	2.6	11.8	1.0
31331	4.5	2.5	46.8	29.6	3.6	13.0	2.5

[1] Approximate. [2] Miller stated that this was not a good separation and was not normal.

TABLE 8.—*Proportion of meats to hulls and of "pops" to normal peanuts.*

Sample No.	Variety.	Hulls.	Meats.	"Pops."
		Per cent.	*Per cent.*	*Per cent.*
29230	Mostly Spanish	25.0	75.0	2.2
29236	do	24.0	76.0	1.3
29238	Spanish and Virginia Runner.	26.0	74.0	6.3
29245	Mostly Virginia Runner	29.4	70.6	7.2
29254	Spanish and Virginia Runner.	25.5	74.5	2.5
29255	do	25.3	74.7	3.0
29293	Mostly Virginia Runner	29.0	71.0	6.3
29296	Spanish	24.0	76.0	4.0
29335	Virginia Runner	29.8	70.2	5.0
31248	Spanish	21.0	79.0	.0
31249	do	23.4	76.6	2.4
31280	do	22.5	77.5	3.0
31283	do	21.7	78.3	.6
31292	do	23.1	76.9	1.2
31302	do	23.2	76.8	8.4
31304	do	21.0	79.0	3.8
31310	do	23.5	76.5	4.6
31317	do	22.0	78.0	5.0
31318	do	23.0	77.0	.0
31323	do	22.0	78.0	2.4
31328	Spanish and Virginia Runner.	23.7	76.3	4.5
31402	Virginia Runner	27.7	72.3	10.0
31405	do	29.0	71.0	2.2
38409	Spanish and Virginia Runner.	24.9	75.1	6.8
Av.		24.5	75.5	

TABLE 9.—*Peanut skins ("red skins" or the coverings of peanut meats).*

Sample No.	Taken from—	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
29634	Peanut-butter plant, Virginia variety.	6.6	4.2	28.6	21.1	9.1	30.4
29145	Peanut-butter plant, Spanish variety.	3.1	2.8	28.4	16.1	11.8	37.8
31228	Confectioners' plant, Virginia variety.	7.3	3.4	30.1	18.1	11.4	29.7
31229	Peanut-butter plant, Spanish variety.	9.1	2.5	31.2	16.5	10.3	30.4
31248	Peanut skins removed by hand, Spanish variety.	9.3	3.0	4.5	12.7	11.2	59.3

TABLE 10.—*Peanut germs ("peanut hearts").*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
31232...	4.5	2.9	45.5	28.8	6.0	12.3
31236...	6.7	3.3	45.8	29.5	3.0	11.7
Av.	5.6	3.1	45.4	29.1	4.5	12.0

TABLE 11.—*Peanut meats.*

Sample No.	Moisture.	Ash.	Ether extract.	Protein.	Fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
29254..........	4.3	2.3	48.0	27.8	2.6	15.0
29335..........	4.4	2.4	48.2	32.2	2.3	10.5
31401..........	4.3	2.3	47.8	29.8	2.8	13.0
31409..........	5.0	2.2	47.1	31.4	2.3	12.0
31239..........	4.4	2.4	50.4	28.5	3.7	10.6
31246..........	5.4	2.5	47.6	30.0	2.7	11.8
31249..........	5.6	2.6	45.6	29.6	3.2	13.4
31250..........	4.4	2.8	45.7	28.7	3.3	15.1
31253..........	4.9	2.6	45.5	29.9	2.6	14.5
31383..........	5.2	2.4	47.6	30.4	2.9	11.5
31297..........	5.4	2.3	46.1	30.6	3.1	12.5
31280..........	5.2	2.6	46.1	30.6	2.4	13.1
31302..........	4.4	2.4	48.2	29.1	2.6	13.3
31304..........	5.2	2.1	48.4	29.5	2.4	12.4
31310..........	4.4	2.5	47.9	28.9	2.5	13.8
31317..........	5.1	2.5	46.0	29.5	3.2	13.7
31318..........	4.5	2.5	47.5	29.5	2.8	13.2
31405..........	4.5	2.7	46.7	28.6	3.1	14.4
31328..........	4.5	2.4	47.1	31.1	2.8	12.1
Average..	4.8	2.4	47.2	29.8	2.8	12.9

The ether-extract determination for the sample of skins removed by hand from the unheated peanuts is noticeably different from that for samples obtained from peanut-butter plants and confectioners' establishments. On this sample the proportion of skins to meats was approximately 2.5 per cent. Sample 29145 contained 0.3 per cent of invert sugars and 2.4 per cent of nonreducing sugars.

The peanut germs analyzed (Table 10) were obtained at peanut-butter plants and confectioners' establishments. They are bitter,

and the fat which they contain breaks up rapidly, becoming rancid, making it necessary to remove them to secure a good product.

The peanut meats analyzed (Table 11) were shelled by hand from peanuts obtained at the warehouse. Sugar and starch determinations were made on one sample of Spanish variety peanuts, with the following results:

	Per cent.
Reducing sugars as invert sugars	0.3
Nonreducing sugars as sucrose	4.7
Starch	4.7
Total sugars and starch	9.7

DEFINITIONS OF PEANUT PRODUCTS.

The Association of the Feed Control Officials of the United States have adopted the following definitions for peanut products:

Peanut-oil cake is the residue after extraction of part of the oil by pressure or solvents from peanut kernels.

Peanut-oil meal is ground peanut-oil cake.

Unhulled peanut-oil feed is the ground residue obtained after extraction of part of the oil from whole peanuts, and the ingredients shall be designated as "peanut meal and hulls."

Peanut-oil meal, being the residue after extracting part of the oil from the peanut kernels, should contain no hulls. A product containing a mixture of meal and hulls should be designated as such a mixture. It is impossible, however, even in the most efficiently run mills, to remove all the hulls by shakers and suction, which is the usual commercial practice. A certain amount of hulls remains in the stock as it goes to the crushers and a much larger amount in the resulting meal. For instance, if the oil content of the stock is 48 per cent and the oil content of the meal is 7 per cent the meal will have 1.8 times as much hulls as the stock which goes to the crushers. Under the present milling conditions, therefore, it is necessary to permit the presence of a certain amount of hulls in a meal in order that the definition may be practical. It follows that a method for determining the percentage of hulls in a meal will be necessary for control work.

A study of Tables 1 and 3 suggests two possibilities for methods for determining the amount of hulls in mixtures of meal and hulls, one based upon the crude-fiber content and the other upon the protein content. The average fiber content of hulls is 67.5 per cent and the average fiber content of pure meal is 4.7 per cent. The average protein content of hulls is 5.4 per cent and the average protein content of pure meal is 51.7 per cent, based on a moisture content of about 7 per cent.

For the purpose of determining hulls from the fiber content and from the protein content in mixtures of meal and hulls the following formulas have been developed:

FORMULA 1.

$$\text{Let } X = \text{the hulls}$$
$$\text{Then } 100 - X = \text{the meal}$$
$$0.675X + 0.047\ (100 - X) = \text{fiber}$$
$$0.628X + 4.7 = \text{fiber}$$
$$X = \frac{\text{fiber} - 4.7}{0.628}$$

FORMULA 2.

$$\text{Let } X = \text{hulls}$$
$$\text{Then } 100 - X = \text{meal}$$
$$0.054X + 0.517\ (100 - X) = \text{protein}$$
$$0.054X + 51.7 - 0.517X = \text{protein}$$
$$-0.463X = \text{protein} - 51.7$$
$$X = \frac{51.7 - \text{protein}}{0.463}$$

TABLE 12.—*Basis for calculating hull content of mixtures of hulls and meal from fiber and protein content.*

Hulls.	Fiber.	Protein.	Hulls.	Fiber.	Protein.	Hulls.	Fiber.	Protein.	Hulls.	Fiber.	Protein.
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
0	4.7	51.7	26	21.0	39.7	52	37.4	27.6	78	53.7	15.6
1	5.3	51.2	27	21.7	39.2	53	38.0	27.2	79	54.3	15.1
2	6.0	50.8	28	22.3	38.7	54	38.6	26.7	80	54.9	14.7
3	6.6	50.3	29	22.9	38.3	55	39.2	26.2	81	55.6	14.2
4	7.2	49.8	30	23.5	37.8	56	39.9	25.8	82	56.2	13.7
5	7.8	49.4	31	24.2	37.3	57	40.5	25.3	83	56.8	13.3
6	8.5	48.9	32	24.8	36.9	58	41.1	24.8	84	57.4	12.8
7	9.1	48.5	33	25.4	36.4	59	41.8	24.4	85	58.0	12.3
8	9.7	48.0	34	26.0	36.0	60	42.4	23.9	86	58.7	11.9
9	10.3	47.5	35	26.7	35.5	61	43.0	23.5	87	59.3	11.4
10	11.0	47.1	36	27.3	35.0	62	43.6	23.0	88	60.0	11.0
11	11.6	46.6	37	27.9	34.6	63	44.3	22.5	89	60.6	10.5
12	12.2	46.1	38	28.6	34.1	64	44.9	22.1	90	61.2	10.0
13	12.9	45.7	39	29.2	33.6	65	45.5	21.6	91	61.8	9.6
14	13.5	45.2	40	29.8	33.2	66	46.1	21.1	92	62.5	9.1
15	14.1	44.8	41	30.4	32.7	67	46.8	20.7	93	63.1	8.6
16	14.7	44.3	42	31.1	32.3	68	47.4	20.2	94	63.7	8.2
17	15.4	43.8	43	31.7	31.8	69	48.0	19.8	95	64.4	7.7
18	16.0	43.4	44	32.3	31.3	70	48.7	19.3	96	65.0	7.3
19	16.6	42.9	45	33.0	30.9	71	49.2	18.8	97	65.6	6.8
20	17.3	42.4	46	33.6	30.4	72	49.9	18.4	98	66.2	6.3
21	17.9	42.0	47	34.2	29.9	73	50.5	17.9	99	66.9	5.9
22	18.5	41.5	48	34.8	29.5	74	51.1	17.4	100	67.5	5.4
23	19.1	41.1	49	35.5	29.0	75	51.8	17.0			
24	19.8	40.6	50	36.1	28.6	76	52.4	16.5			
25	20.4	40.1	51	36.7	28.1	77	53.0	16.0			

From the figures given in Table 12, obtained by applying these formulas, it is possible to determine the hull content of a mixture of meal and hulls from the fiber content or the protein content. These determinations can be only approximations, since the fiber in hulls and the protein in the meats vary somewhat. They are accurate enough, however, to be of value in control work and are the only measuring sticks for hulls known at present. The methods are not sufficiently accurate to make it worth while to reduce the products to an equal oil basis, as the oil in the meals does not vary

enough to make any material difference. Similar methods of calculation have been suggested in Texas Agricultural Experiment Station Bulletin 22, "The Composition of Peanuts and Peanut By-products." The method based on the fiber content will probably be more accurate

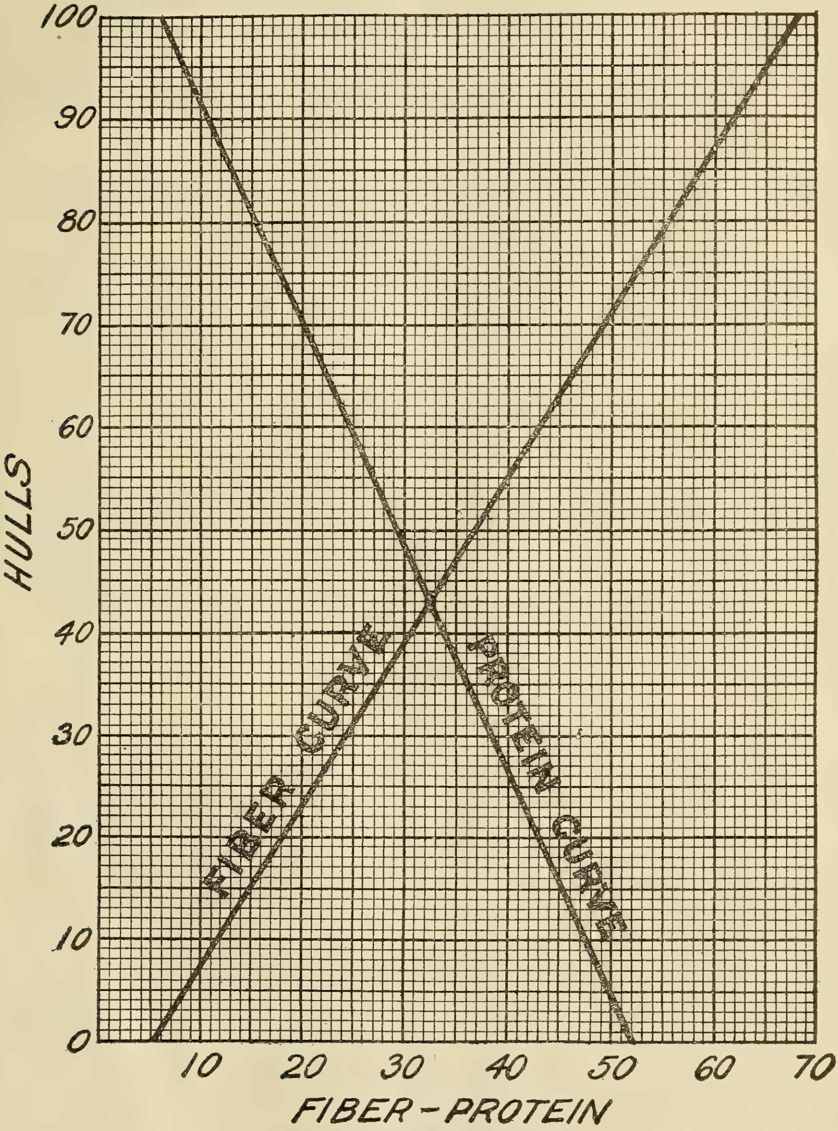

FIG. 1.—Relation of fiber content and protein content to hulls.

than the one based on the protein content, since hulls consist largely of fiber. From the curves in Figure 1 hulls can be determined at a glance from either the fiber content or the protein content.

The crushing of whole peanuts is usually done by the expeller process. The results in Table 2 indicate that a product containing from 34.4 to 38.6 per cent of protein is obtained. There seems to be a tendency in the industry to consider this product as peanut meal, although it is not, but is peanut meal and hulls, as is also any product which contains hulls over and above the amount that would naturally be unavoidably left in the feed by an efficiently run mill. Often manufacturers who crush by the hydraulic method and remove all the hulls possible before crushing grind back into this product either all the hulls or a part of them. They feel that such a product is properly designated as peanut meal, although such is not the case.

The cause of the wide variation in the percentage of protein in products obtained by crushing whole peanuts is the presence of varying quantities of "pops" in the stock. These are pods which contain no meats and are nothing more or less than hulls. Consequently, when peanuts with a large proportion of "pops" are crushed the resulting cake contains more fiber and less protein than that obtained from normal peanuts. If hulls are determined from the fiber and protein content by the formulas on page 10 a higher percentage of hulls will be obtained than if the peanuts had been normal.

The results in Table 5 show that in mills where hulls have been removed by suction the meals obtained contain from 45.3 to 49 per cent of protein and from 4.6 to 11.2 per cent of fiber, indicating from the fiber determinations the presence of from none to approximately 10.3 per cent of hulls in the meals.

SUMMARY.

Crushing whole peanuts by the expeller process usually gives a meal containing from 34.4 to 38.6 per cent of protein. Crushing peanuts from which the hulls have first been removed by the hydraulic process gives a meal containing from 45.3 to 49 per cent of protein.

Peanut meal is an excellent feed. Peanut hulls, however, have a low feeding value and can not be economically shipped any great distance for use as a feed.

It is possible to determine approximately the percentage of hulls in a mixture of peanut meal and hulls, either from the fiber content or from the protein content. It is probable, however, that the figures obtained from the fiber content will be more nearly accurate.

The composition of peanut skins removed by hand differs from that of peanut skins obtained from the peanut-butter plants. The composition of peanut germs is similar to that of the meats, with somewhat lower oil and somewhat higher ash contents.

A sample of meats from the Spanish variety of peanuts was found to contain 5 per cent of sugars and 4.7 per cent of starch.

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THE EFFECT OF SILAGE ON THE FLAVOR AND ODOR OF MILK.

By JAMES A. GAMBLE, *Professor of Dairy Husbandry, University of Maryland, collaborator, and* ERNEST KELLY, *in charge of Market Milk Investigations, Dairy Division, Bureau of Animal Industry.*

CONTENTS.

CAUSES OF TAINTS IN MILK.

Cow's milk invariably has a more or less pronounced flavor and odor, but comparatively little is known concerning the substances contributing to these characteristics. The flavors vary from those that are pleasing to the taste to others which make the milk objectionable and unpalatable. It has been observed by several investigators that regardless of the feeds used and care taken, each cow imparts to her milk a more or less pronounced individual taste. In a row of cows receiving the same feed and care, the authors have observed bitter, strong, salty, and flat milk as well as that having a very pleasing flavor. Several of these if sold alone would have been rejected

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by consumers, yet when all were blended into the mixed milk of the herd, the resulting blend was pleasing to the taste.

Flavors and odors in milk result from four causes:

1. The internal or physical condition of the individual cow.
2. Those absorbed within the body of the cow from highly flavored feeds.
3. Odors absorbed into the milk after production.
4. Bacterial development within the milk on standing.

Flavors and odors of the first and second classes are more noticeable just after the milk is drawn and usually do not increase with time. Those of the fourth class become more apparent after some time has elapsed. This bulletin considers principally the factors in Groups 2 and 3, although information regarding Group 1 is brought out by the investigation.

Milk of pleasing quality is usually produced on farms making a specialty of high-grade milk. On the other hand, the great bulk of the country's supply is produced on farms where milk production is but one of several farm activities, and, as a result, less time is available for controlling the factors which affect deleteriously the flavor and odor of milk. With the exercise of a few precautions, however, some of the defects found in market milk may at least be alleviated.

Factors affecting the flavors and odors of milk have been investigated extensively, and much excellent work pertaining to the subject published. However, such work has largely dealt with the subject in a general way. The authors of this bulletin have studied the problem from a somewhat different angle. The endeavor has been to suggest methods of assistance to the average dairyman in the production of milk reasonably free from the feed taints too frequently complained of in market milk.

The objects of this investigation therefore may be outlined as follows:

1. To determine whether or not the feeding of the different silages does affect the flavors and odors of milk.
2. If such is the case, to determine how these silages may be so fed and and the milk so handled as to minimize their effect on the quality of the product.

DESCRIPTION OF METHODS USED IN EXPERIMENTAL WORK.

For the experiments, a small barn was constructed at the United States Department of Agriculture Dairy Experiment Farm at Beltsville, Md. The building was of wooden construction throughout and was divided into two parts, one part providing space for four cows. The material used for floors, walls, and ceiling was No. 1 tongue-and-groove pine. Building paper was placed on the outside walls of the part used for a stable to make the building as free as possible from drafts. Ventilation was provided by doors and windows.

The stable contained approximately 250 cubic feet of air space for each of four cows, or about one-half the air space required by

most city regulations. The object was not only to get a milking chamber which would hold odors, but, by cutting down the space one-half, to intensify still further the degree of feed odors in the stable air. This condition was necessary during the absorption work of the investigation. The silo was at a considerable distance from this barn.

Four cows, each giving about 10 pounds of milk daily, of approximately 4 per cent butterfat, were selected from the Dairy Division herd. Only those animals which gave milk free from decided off flavors and off odors were selected and these were transferred to the small barn. The milk in all cases was drawn by milkers who gave close attention to the cleanliness of the cows and stable and of their own hands. The cows were alternated from time to time in order to equalize any abnormal results due to the milk of any individual animal. For example, in working with the first absorption phase, each pair of cows was milked outside the barn on alternate afternoons. At intervals, the individuals in each pair were interchanged.

During these experiments the cows when producing the check samples were fed on a basic grain and hay ration which did not appreciably affect the flavor and odor of the milk they produced.

In all the work, the milk from the different pairs was drawn into sterilized, covered pails, and the milk from each pair strained through filter cloth into a separate can that had been sterilized. The utensils were steamed in a sterilizer for 30 minutes, and afterwards allowed to remain there until used.

METHOD OF SAMPLING.

After milking, the two cans of milk were promptly carried from the barn to the milk room, the milk in each can stirred, and samples taken. The milk from each pair of cows was emptied into a gravity creaming can and with the samples was placed in a refrigerator which cooled and held it below 50° F. The next morning the skim milk in the different cans was drawn off and samples of the cream taken.

When the effect of aeration was studied, half of the warm milk from each pair of cows was aerated by passing it over a clean surface cooler, the milk resampled, the remainder placed in the refrigerator, the milk allowed to cream, the skim milk drawn off, and the cream also sampled.

When, in addition, it was desired to get a standard sample known to contain the flavor and odor of silage, part of the milk from the cows not fed silage and not exposed to the silage odor in the milking barn, while still warm, was redrawn through an apparatus containing the silage odor. This apparatus is shown in Figure 1. Ten pounds of silage, fresh from the silo, were placed in this closed chamber an hour before the redrawing took place.

The warm milk was poured into the funnel erected on top of this box, and redrawn through the openings into a container resting on the silage within the chamber. The odor arising from the silage in

FIG. 1.—Apparatus for drawing samples of milk through atmosphere saturated with silage odor.

the closed chamber imparted to the warm milk, which was passing through it. a decided silage flavor and odor. A portion of this was drawn, cooled. and delivered with the other samples. All samples

were examined by men in the Dairy Division of the United States Department of Agriculture and members of the Dairy Husbandry Department of the University of Maryland.

METHOD OF EXAMINATION.

Flavors and odors are more apparent when the milk is at body temperature. For this reason all samples, before being submitted to the different judges, were heated in a water bath to about body temperature.

Some flavors and odors, because of familiarity, are quickly recognized by some people, and because of unfamiliarity may not be so quickly recognized by others. Standard samples of silage-flavored milk were provided to supply this information. When the portions were warmed and ready for examination, the sample containing the known silage flavor and odor was passed around and examined, so that the different men might have a measure for determining whether or not any of the other samples contained a silage flavor or a silage odor or both. Each man was furnished with slips upon which to record the flavor and odor in the different samples submitted to him. At the end of each phase of the work, the information on these slips, when compared to the key containing the history of each sample, furnished a basis for conclusions.

THE FEEDING OF SILAGE.

Ever since silage came into use as a feed for dairy cattle more or less controversy has taken place regarding its effect on the flavor and odor of the milk produced. It has frequently been said that the feeding of silage to milking cows gives rise to disagreeable flavors and odors. So much has appeared on the subject that health authorities in some cities have incorporated in their city milk laws regulations relating to the handling and sale of milk produced by cows fed silage.

EXPERIMENTS WITH CORN SILAGE.

During the first three weeks that the cows were in the specially constructed barn experiments were carried on for the purpose of determining the combination of concentrates and roughage for a basic ration which would not interfere with the flavor and odor of the milk normally produced by the cows selected for the work. When this combination had been obtained the barn and the cows were carefully cleaned.

1. EFFECT OF CORN-SILAGE ATMOSPHERE ON FLAVOR AND ODOR OF MILK.

On alternate days 2 cows were removed to the outside one hour before milking and 150 pounds of corn silage, fresh from the silo,

was spread on the platform underneath the 2 cows remaining in the stable and the doors and windows tightly closed. During the interval before milking, the silage odor so permeated the stable air that by the time milking was started a decided silage odor was present. It will be noted that the quantity of silage spread out would have been equivalent to 75 pounds per cow in an air space of approximately 500 cubic feet. Table 1 shows the result of the experiment.

Particular attention is called to the extreme condition of barn-air saturation used in this experiment. This exaggerated condition was obtained for the purpose of ascertaining whether or not the so-called silage flavor and odor might be air-borne to milk under extreme barn conditions. No legitimate excuse can be conceived for the production of milk in a barn without ventilation or with the small amount of air space used in this work to determine the above point. Manure was removed once each day and the barn thoroughly aired.

TABLE 1.—*Effect of milking in stable air saturated with silage odor.*

Result of sampling.	Cows milked in silage atmosphere.		Check cows milked in open air.	
	Milk.	Cream.	Milk.	Cream.
Number of examinations	415	415	415	415
Off flavor	96	103	51	57
No off flavor	319	312	364	358
Off odor	51	77	19	31
No off odor	364	338	396	384

One of the most interesting points brought out was that although in at least one-fourth of the cases the milk produced by the cows milked in the barn under these extreme conditions took on the off flavors and odors present in the barn air to a sufficient degree to become apparent to those looking carefully for them, it certainly did so to a less extent than is commonly supposed. The terms used in describing the off flavors and odors were, "barny," "flat," "slightly off," "off," "slightly strong," and "slight feed." It was observed that flavor and odor in the milk were designated by the matter with which they were associated. The off flavors and odors were found more often in the cream than in the milk. This would indicate that the fat of the milk absorbs off flavors to a greater degree than the milk plasma.

While off flavors were noted in approximately one-fourth of the cases, a large percentage of these were reported as "barny," "strong," and "off," with but few notations of "slight feed."

The terms used to describe the odors of the milk produced in the closed stable were the same as those used to describe the flavors, except that the terms "barny" and "musty" were used more often.

From this work it is apparent that under these extreme conditions, not approached on dairy farms, the silage flavor and odor may, to a limited extent, be air borne to milk during production.

"Natural," "normal," "good," and "excellent" were the terms used in describing the flavor and odor of the milk produced outside of the stable by the check cows in almost 90 per cent of the cases. In 45 out of 415 examinations, "slightly flat," "flat," "slightly salty," "slightly off," and "off" were used, and in 6 cases the term "slight feed." All these terms except the last are employed in describing what are known as individual flavors. If we assume that a like number of the 96 off flavors in the milk produced inside the stable were also individual taints, this would reduce the possible number affected by the barn air in Table 1 to 51 samples out of 415, leaving 364, or close to 90 per cent, which did not absorb sufficient silage odors during the milking in the closed stable to be discernible to those looking carefully for such flavors.

2. FEEDING CORN SILAGE BEFORE MILKING IN UNVENTILATED BARN.

Having determined the effects of an intense silage atmosphere on the flavor and odor of milk under the extreme conditions which prevailed in Experiment No. 1, the next step was to determine the effects under extreme conditions on the farm. In this experiment the air saturation arose from the silage which was fed to the cows in the barn. The cows were given all the corn silage they would consume, each cow receiving from 30 to 50 pounds in two feedings—one hour before milking in the morning and one hour before milking at night. The barn doors and windows were closed after each feeding. During this experiment the milk and cream samples were examined by 39 different men.

TABLE 2.—*Effect of feeding 15 to 25 pounds of corn silage per cow before each milking in an unventilated barn.*

Result of sampling.	Cows fed silage.		Check cows not fed silage.	
	Milk.	Cream.	Milk.	Cream.
Number of examinations	346	346	346	346
Off flavor	313	315	30	30
No off flavor	33	31	316	316
Off odor	318	317	29	30
No off odor	28	29	317	316

In almost 90 per cent of the cases the terms used in describing the flavors present in the milk from cows fed silage were "very slight feed," "slight feed," "feed," "strong feed," "sweet," "fermented," "malt," "slight silage," and "silage." From this it is apparent that

when from 30 to 50 pounds of silage were fed daily to cows in two feedings, one hour before each milking, in an unventilated barn, a feed flavor and odor were imparted to the milk of the cows receiving silage.

The flavors and odors in the milk and cream from the alternate cows not receiving silage were usually described as "good," "excellent," "mild," "natural," and "normal." The milk from the cows not fed silage furnished a check on the effects of the odors present in the barn air. Table 2 shows conclusively that when cows were kept in an unventilated barn in which the corn-silage odor was present to a greater degree than under reasonably good farm feeding conditions the examiners, looking painstakingly for such, did not find a feed flavor and odor except in a comparatively few cases. These were silage taints probably due to carrying over such taint within the body from previous feeding, as demonstrated in subsequent experiments. These results show that the more or less common opinion that silage flavors are air-borne to milk is not true to the degree commonly supposed. They also show that milk from cows fed silage under the conditions of this experiment does take on, through the body, the silage flavor and odor.

3. FEEDING 10 POUNDS OF CORN SILAGE BEFORE MILKING.

Having determined that the odor of corn silage is usually body-borne to milk, the next step was to ascertain the number of pounds of corn silage which could be fed to cows one hour previous to milking before such milk would take on sufficient silage flavor and odor through the body to be recognized by those looking carefully for the same. Table 3 shows the result from samples drawn from the mixed milk of cows each receiving 10 pounds of silage. The barn was well ventilated in this and all experiments which follow.

TABLE 3.—*Effect of feeding 10 pounds of corn silage per cow once a day one hour before milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number of examinations	51	51	51
Off flavor	44	38	2
No off flavor	7	13	49
Off odor	41	35	2
No off odor	10	16	49

The flavors and odors of milk from the cows fed silage were described as "slight feed," "sweetish feed," or "silage." These results show that the feeding of 10 pounds of corn silage to cows one hour before milking gave the milk a sufficient feed flavor to be recog-

nized in over 85 per cent of the cases. Although sufficient flavor and odor were present in the milk to be detected in this number of cases by men examining the milk carefully, it is probable that the feeding of 10 pounds of silage, as above, did not affect the milk sufficiently to be noted by the average consumer.

EFFECT OF AERATION.

To determine the effect of aeration on the feed flavor and odor present, the same milk, after being sampled and while still warm, was passed over a surface cooler and resampled. The results in Table 3 show that when the milk was aerated a part of the feed flavor and odor it contained was removed. The table shows that, in the aerated milk, feed flavors and odors were noted in six samples fewer than in the milk before aeration. They were reduced in degree also in the other samples.

The cows not receiving silage occupied and were milked in alternate stalls from those receiving silage. In the table it is seen that in over 96 per cent of the cases no feed flavor or odor was observed in the milk drawn from cows standing in the same barn side by side with the cows fed silage.

This experiment shows that the feeding of 10 pounds of corn silage one hour before milking gave a perceptible feed flavor and odor to the milk. It further shows that if such milk is carefully aerated while still warm, the degree of flavor and odor may be materially diminished. In the opinion of the judges, the silage flavor present in the milk often enhanced rather than detracted from its palatability.

4. FEEDING 20 POUNDS OF CORN SILAGE BEFORE MILKING

In the next experiment, the quantity of corn silage fed before milking was increased to 20 pounds.

TABLE 4.—*Effect of feeding 20 pounds of corn silage once a day one hour before milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number of examinations	25	25	25
Off flavor	18	18	0
No off flavor	7	7	25
Off odor	25	20	0
No off odor	0	5	25

The results in Table 4 show that the feeding of 20 pounds of corn silage each to cows one hour before milking gave the milk sufficient feed flavor or odor to be detected in all of the samples. The flavors

and odors present were described as "slight feed," "feed," "silage," and "strong feed."

During the latter part of this experiment it became necessary to use silage which had been in the silo for four or five years. This silage had a milder flavor than the 8-month-old silage fed in 10-pound lots during the previous experiment, and gave the milk a milder silage flavor. This suggests that the degree of odor present in the silage helps to determine the degree of feed flavor and odor imparted to milk.

EFFECT OF AERATION.

After the samples of milk from the silage-fed cows were taken, the remaining milk, while still warm, was aerated by passing it over a surface cooler. Although diminished by aeration, the feed odor was still present in sufficient degree to be noted in over 70 per cent of the flavor examinations and in 80 per cent of the odor examinations.

Table 4 also shows the conditions noted in the check samples from cows not fed silage. The terms used by the judges in describing the flavor and odor in these samples were "natural," "normal," "good," and "excellent." In no cases were the judges able to detect any feed flavor or odor in the milk drawn from the cows not receiving silage. This agrees with previous work covering this phase.

It is apparent that feeding 20 pounds of corn silage one hour before milking does affect the flavor and odor of milk to an appreciable extent. It is also apparent that aeration diminishes the degree of the feed odor imparted by the silage. The experiment further suggests that when 20 pounds of 5-year-old silage are fed, sufficient will pass through the body to affect the taste and smell of the milk produced. While the feed flavor and odor in this milk were sufficiently prominent to be apparent to some consumers, it was the opinion of the judges that after aeration it would be accepted in a great many cases without complaint on the part of the consumer.

5. FEEDING 30 POUNDS OF CORN SILAGE BEFORE MILKING.

The quantity of silage was next increased to 30 pounds per cow.

TABLE 5.—*Effect of feeding 30 pounds of corn silage once a day one hour before milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number of examinations	46	46	46
Off flavor	46	46	1
No off flavor	0	0	45
Off odor	46	46	1
No off odor	0	0	45

The flavors and odors in the milk of the silage-fed cows were noted as "fermented feed," "feed," or "slight silage," "silage," or "strong feed" in all cases. The results in Table 5 show that milk from cows fed 30 pounds of corn silage before milking had a decided feed flavor and odor. The taste and smell of the feed were noted in every case by all the judges. In the opinion of these men, sufficient was present to be noted by even those consumers giving but little attention to the flavor and odor of the milk supplied them.

EFFECT OF AERATION.

Although a feed flavor and odor were noted by all the men who passed upon the aerated milk, the degree present was diminished. This shows that when silage is fed in these quantities just before milking, aeration may be of much assistance in decreasing the flavor and odor of silage.

The milk from the other 2 cows in the barn in alternate stalls from those fed silage was examined as a check on the barn air and the basic ration which all the cows were receiving.

Comparing the results in this experiment with those obtained in Experiment No. 2, the effect of the new factor, ventilation, on the flavor and odor of milk produced by cows not fed silage is strikingly shown. (Compare the columns for the check cows in Tables 2 and 5). Proper ventilation may play an important part in ridding the barn of manure odors. Adequate ventilation is, therefore, important in limiting undesirable flavors and odors which may be absorbed during milking.

This experiment also shows that feeding 30 pounds of corn silage one hour before milking gives the milk a feed flavor and odor sufficient to render it objectionable to most consumers. Another point brought out was that, whether silage is fed immediately after being taken from the silo or allowed to air somewhat before feeding, the milk produced carries strong feed flavor and odor. This feed flavor and odor had a tendency, however, to be stronger in the milk when the silage was fed fresh from the silo. Even when as low as 10 pounds of silage per cow were fed a silage flavor was imparted to 85 per cent of the samples in a sufficient degree to be noted by those looking carefully for it. The degree of flavor, however, was much less than when 20 or 30 pounds were fed in a like manner. It may be said that not until 20 pounds or more were fed did the feed flavor and odor become so pronounced as to make the milk decidedly objectionable to a majority of consumers. In fact, it was the opinion of the judges that the flavor imparted when 10 pounds of corn silage were fed enhanced the palatability of the milk.

It was apparent that the greater the quantity of silage fed before milking the more pronounced the feed flavor and odor. The ob-

servers noted that aeration diminished the degree of silage flavors and odors to a greater extent as the quantity of silage fed was increased.

6. FEEDING CORN SILAGE AFTER MILKING.

The practice of feeding silage after milking is recommended by practically all authorities. The next step in this work was to determine the quantity of corn silage that could be fed after milking and not deleteriously affect the flavor and odor of the milk produced. Two of the cows were fed all the corn silage they would consume in two feedings per day one hour after milking. One of these individuals refused more than 30 pounds or 15 pounds at a feeding, while the other readily consumed 50 pounds in two feedings of 25 pounds each. The milk from these cows, when mixed, represented an average consumption of 40 pounds of silage per cow each day.

TABLE 6.—*Effect of feeding 15 to 25 pounds of corn silage twice daily one hour after milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number of examinations	25	25	25
Off flavor	15	2	1
No off flavor	10	23	24
Off odor	12	2	1
No off odor	13	23	24

The results in Table 6 show that when an average of 20 pounds of corn silage per cow was fed just after each milking the milk took on a slight feed flavor or odor in more than 50 per cent of the cases. The flavor and odor detected were described as "slight feed" and "slight silage." This shows that while the feeding of corn silage after milking is to be recommended, such a practice does affect both flavor and odor when fed under conditions similar to those prevailing in this experiment. It appears also that while men accustomed to examining milk closely detected a slight feed flavor and odor, it was present in quantities too small to be objectionable to the average consumer, as 40 per cent of the samples did not show these characteristics sufficiently to be detected when the milk was carefully examined by experienced men.

It is interesting also to note that in the opinion of the majority of the judges, the slightly sweetish flavor imparted enhanced rather than detracted from the palatability of the milk. In no case were the feed flavors and odors present to as great a degree as was found in the samples from cows fed 10 pounds of silage one hour before milking.

EFFECT OF AERATION.

This milk was afterwards aerated, resampled, and examined. After aeration, instead of 50 per cent of the samples containing a recognizable feed flavor and odor, it was observed in less than 10 per cent of the samples. From this we may conclude that careful aeration of the warm milk from cows fed up to 20 pounds of silage, twice daily after milking, will materially reduce the degree of feed flavor present. Cows are usually fed less than 50 pounds per cow per day. If this is fed after milking, and the milk carefully aerated, it is probable that the feed flavors and odors present will be so slight as to be passed by the average consumer without observation. It must be recognized, however, that this work was done with carefully made silage. It is also probable that the sudden feeding of corn silage in quantities as great as 40 pounds a day to a cow not accustomed to receiving it might have a more decided effect on the flavor and odor of milk for the first few days, or until the cow's stomach became accustomed to handling this quantity. It was noted that as each phase of the work with silage progressed the feed flavor and odor were detected less frequently by the judges, even though the same quantity was fed from day to day.

As a check on the cows fed silage, the milk from the other pair standing side by side was sampled. The flavors and odors of these check samples, with one exception, were described as "normal," "natural," "mild," "good," and "excellent."

EFFECT OF CONDENSING ON SILAGE-FLAVORED MILK.

Ten gallons of milk from cows not receiving silage was passed through a saturated silage atmosphere in the apparatus shown in Figure 1. This gave the milk a more decided silage flavor and odor than was observed when silage was fed even under the extreme conditions of Experiment No. 2. The milk was then condensed in a commercial apparatus and the resultant product sampled.

In the early days several large firms buying milk for condensing purposes discriminated against milk from cows fed corn silage. This examination was conducted to secure information on the effect of silage on condensed milk. It was noted by all the judges that the distillate taken from the silage milk during condensing contained a concentrated silage flavor and odor, much more so than the milk itself before condensing. It was noted also that the condensed milk had much less silage flavor and odor than the milk from which it was manufactured.

FEEDING SPOILED SILAGE.

Dairymen are frequently warned by authorities not to feed spoiled silage because of its effect on the milk flavor. Experiments were

carried on with the feeding of decomposed silage taken from the top of a silo when it was opened. From 5 to 15 pounds of this material were fed to each cow one hour before milking. It was noted that 5 pounds of this imparted a very strong flavor and odor to the milk, described as "resembling garlic" by several of those who passed upon it. As much as 15 pounds of this material was eaten readily by the cows under experiment. Even after aeration it was found that when the quantities fed were as low as 5 pounds, sufficient of the objectionable flavors and odors remained to render the milk objectionable to the consumer.

DISCUSSION OF CORN-SILAGE EXPERIMENTS.

It is apparent that under the feeding conditions in these experiments the danger of tainting milk during production by exposure to stable air containing the odor of silage is not so important as some have stated. It is shown, however, that ventilation plays an important part in preventing the tainting of milk during milking, and, further, that milk should be removed from the stable immediately after it is drawn. Statements have been made, and possibly it has been the general belief, that the greatest source of silage flavors and odors in milk is silage-tainted barn air. These experiments show that silage flavors and odors are almost wholly taken up by the milk within the body of the cow. Whether silage is fed before or after milking, the barn should be carefully ventilated before milking is started.

In the feeding of silage before milking, these experiments show that when as little as 10 pounds to a feed was given, the milk took on through the body of the cow a faint feed flavor and odor. As the quantity was increased to 30 pounds at a feed, the degree of silage flavor and odor was likewise increased. It is also shown that careful aeration materially reduced the degree of both feed flavor and odor.

This confirms the work of Knisely (*8*[1]) who reports that milk from cows fed corn silage has a more pronounced odor than milk from cows fed hay. King (*7*) also states:

> It was demonstrated beyond question that when silage is fed a short time before milking, a sweetish odor is imparted to milk.

An article in Hoard's Dairyman (*1*) states:

> If silage is fed before milking, there is likely to be a silage odor in the milk.

Many other workers have also pointed out these truths during the last 20 years.

In the feeding of silage after milking, our results do not entirely agree with some other workers. It was found that when as little as

[1] The italic figures in parenthesis refer to Literature Cited at end of bulletin.

30 pounds daily was fed in two feeds after milking, the milk from the cows showed a slight feed flavor and odor, and that when more than 40 pounds per day were fed to cows, their milk carried continuously a slight silage flavor and odor. In this connection, it is again pointed out as reported by Henry and Morrison (*6*), that as feeding progressed the effects of the silage become less and less apparent in the milk. In our work it was found that while this was true when less than 35 pounds per day was fed to each cow, it was shown that when over 40 pounds were consumed, the sweetish feed flavor could always be detected. King (*7*) reports:

> It was demonstrated that if silage is fed to cows just after milking, in a majority of cases, milks so produced could not be separated by the sense of smell from nonsilage milks.

Farrington (*3*) reports:

> It has been repeatedly proved that silage can be fed to dairy cows without tainting the milk, butter, or cream in the slightest.

The presence of a small but discernible amount of silage flavor in milk need not perplex, however, for it is shown that careful aeration will reduce this to a point where the feed flavor and odor will not be detected by the average consumer.

Moderate quantities of corn silage properly fed to milking cows have a tendency to enhance rather than to detract from the flavor and odor of the milk. This is especially true of individual milks normally flat or lacking in flavor.

EXPERIMENTS WITH ALFALFA SILAGE.

It frequently happens that farmers have difficulty in curing alfalfa for hay. The first cutting is sometimes so full of weeds that it dries slowly; in other cases a wet season interferes, while at other times a threatening early frost makes immediate cutting of the last crop expedient. Putting the green alfalfa into the silo has in many cases meant saving the crop.

While some dairymen have used alfalfa silage with success, others claim that milk spoilage is experienced. However that may be, a great deal of alfalfa silage is now being fed. The experiments next described were carried out to determine how this roughage, rich in protein, may be fed so as to affect least deleteriously the flavor and odor of the milk produced.

The alfalfa silage used was made from finely cut green alfalfa, carefully packed in the silo.

1. FEEDING ALFALFA SILAGE BEFORE MILKING.

The first work covered the feeding of 5 pounds of alfalfa silage one hour before milking. This quantity was gradually increased to

20 pounds per cow. The cows on experiment would not consume more than this weight at a feeding.

TABLE 7.—*Effect of feeding 5 to 20 pounds of alfalfa silage once daily one hour before milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number of examinations	11	11	11
Off flavor	11	11	0
No off flavor	0	0	11
Off odor	11	11	0
No off odor	0	0	11

The results in Table 7 show that the feeding of alfalfa silage to cows one hour before milking imparted a feed flavor which could be detected in all cases. The off flavors were described as "slight feed," "feed," "slight silage," and "alfalfa silage" as the quantity was increased up to 20 pounds. The odors were described with the same terms. When the milk from the cows receiving 5 pounds was aerated the flavor and odor were very faint. When 10 pounds per cow was reached, the milk contained sufficient feed flavor and odor even after aeration to be ordinarily detected by consumers. When 15 pounds had been reached sufficient was present, in the opinion of the examiners, to cause rejection of the milk by the average consumer. Without question, the cream from this milk would be rejected by the sweet-cream trade.

EFFECT OF AERATION.

In this experiment it was noted that while aeration removed a great part of the feed taste and aroma, sufficient remained to be noted in all examinations.

Standing in the barn in alternate stalls were the cows which did not receive alfalfa silage. It is seen in the table that no feed flavor or odor was noted in the milk produced by these cows. It is to be remembered, however, that throughout this work, with the exceptions of Experiments Nos. 1 and 2, the barn was well ventilated.

2. FEEDING ALFALFA SILAGE AFTER MILKING

As in the feeding of corn silage the importance of feeding alfalfa silage only after milking has been noted. To determine how much of this may be fed per cow, after milking, without rendering the milk objectionable to consumers, the following work, shown in Table 8, was carried on.

TABLE 8.—*Effect of feeding 5 to 20 pounds of alfalfa silage once daily one hour after milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number examinations	14	14	14
Off flavor	10	5	0
No off flavor	4	9	14
Off odor	8	5	0
No off odor	6	9	14

In this experiment 5 pounds were fed to begin with, and this quantity increased 5 pounds every two days up to 20 pounds, when it was reduced to 5 pounds again, dropping 5 pounds every two days. It was observed that the alfalfa-silage flavor did not become noticeable in the milk until 10 pounds or more were fed. However, when from 15 to 20 pounds were consumed at each feeding the milk took on a decided feed flavor and odor.

When this milk was aerated the degree of feed flavor and odor was decidedly reduced and was detected less often, as shown in the table. This again shows the importance of aerating milk. It was also observed that when the milk from cows receiving 10 pounds was aerated all judges failed to detect feed flavors or odors.

This work indicates that alfalfa silage should be fed only after milking, and that the milk should be well aerated while still warm. The importance of this is shown by comparing the results in Table 7 with those obtained in Table 8.

EXPERIMENTS WITH SWEET-CLOVER SILAGE.

In some cases clover crops have been made into silage with fair success. Where weather conditions interfere with the proper curing of clover for hay it is sometimes put into the silo. It is well known that the silage made from clover has a strong odor, necessitating careful feeding to avoid tainting the milk. For this experiment silage made from sweet clover, cut in fine lengths and tramped solidly, was fed to the experimental cows. It was noted that the sweet-clover silage had a more decided odor than the alfalfa silage.

1. FEEDING SWEET-CLOVER SILAGE BEFORE MILKING.

At the beginning of the work 5 pounds of sweet-clover silage were fed one hour before milking. This was continued for several days; afterwards the quantity was increased to 10 pounds and continued for several days longer; then increased to 15 pounds. An effort was

made to increase the feeding to 20 pounds, but the cows refused to consume that quantity at a feed. It was noted that even when 5 pounds were fed in nearly all cases the milk had a detectable feed flavor and odor, and when the quantity was increased to 15 pounds the feed flavor and odor became very objectionable.

TABLE 9.—*Effect of feeding 5 to 15 pounds of sweet-clover silage once daily one hour before milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number of examinations	30	30	30
Off flavor	28	20	0
No off flavor	2	10	30
Off odor	29	21	0
No off odor	1	9	30

EFFECT OF AERATION.

When the milk from the cows fed up to and including 15 pounds before milking was aerated, the intensity of the feed flavor and odor was diminished, as shown in the table. In the opinion of the judges sufficient of the feed flavor and odor had been removed during aeration to render the milk palatable.

This experiment shows that even as little as 5 pounds of sweet-clover silage, when fed before milking, produced a feed flavor; 10 pounds produced a decided feed flavor and odor, and 15 pounds so increased the intensity as to render the milk, if unaerated, objectionable to the average consumer. It is also shown that aeration so reduced the flavor and odor present, when 5 pounds were fed, as to cause it largely to disappear. When 10 pounds were fed and the milk aerated, the sweet-clover silage flavor and odor persisted. When 15 pounds were fed and the milk aerated, while the flavor and odor was somewhat stronger, a decided reduction in the degree had taken place. In the case of this silage, the odor, after aeration, seemed more tenacious than the flavor.

In this experiment, as in others, check results were obtained with alternate cows not fed silage. There was a total lack of feed flavor and odor in the milk from these cows.

2. FEEDING SWEET-CLOVER SILAGE AFTER MILKING.

The next experiment was carried on to ascertain the quantity of sweet-clover silage that could be fed after milking and the methods of handling necessary to overcome the objectionable effects.

TABLE 10.—*Effect of feeding 5 to 15 pounds of sweet-clover silage once daily one hour after milking.*

Result of sampling.	Milk from cows fed silage.		Milk from cows not fed silage.
	Before aeration.	After aeration.	
Number of examinations	30	30	30
Off flavor	28	20	2
No off flavor	2	10	28
Off odor	29	21	2
No off odor	1	9	28

The results with unaerated milk show that when sweet-clover silage was fed after milking in quantities from 5 to 15 pounds, a feed flavor and odor were imparted to the milk. In explanation of this table it may be said that in 2 cases there were no feed flavors and in 1 case no feed odor when 5 pounds were fed. When this quantity was increased to 10 pounds, the notations were, "slight silage," and "slight feed"; when 15 pounds were fed the samples were marked "feed," "strong feed," and "clover silage." While the feeding of sweet-clover silage is a desirable practice from an economic standpoint, the above results show that even when fed under ideal conditions it affected the flavor and odor of the milk produced, 15 pounds, fed after milking, tainting the milk sufficiently to be noted by the average consumer.

EFFECT OF AERATION.

Aeration, however, produced a marked change in the degree of the flavors present. By sprinkling the grain ration on the sweet-clover silage, each cow consumed up to 15 pounds of silage at a feeding. When this milk was aerated, in the opinion of the judges, the feed flavor was sufficiently diminished to be unobjectionable to the average consumer. These results show that sweet-clover silage should be fed only after milking, and the milk should be carefully aerated while still warm. When this is done, up to 15 pounds at each feeding may be fed per cow without permanently injuring the commercial value of the product.

EXPERIMENTS WITH SOY-BEAN SILAGE.

Another protein roughage, soy beans, is also sometimes ensiled. When put in the silo alone soy beans make rank-smelling silage. The effect of this feed on the flavor and odor of milk is shown in the following experiments.

1. FEEDING SOY-BEAN SILAGE BEFORE MILKING.

In feeding this material it was noted that 5 pounds gave the milk a detectable feed flavor and odor. As the quantity was increased to 15 and 20 pounds, the flavors and odors present increased in intensity.

TABLE 11.—*Effect of feeding 5 to 20 pounds of soy-bean silage once daily one hour before milking.*

Result of sampling.	Milk from cows fed silage.	Milk from cows not fed silage.
Number of examinations	16	16
Off flavor	16	1
No off flavor	0	15
Off odor	16	2
No off odor	0	14

The milk from cows not receiving soy-bean silage was scored, as usual, for a check, with the results shown in the table.

2. FEEDING SOY-BEAN SILAGE AFTER MILKING.

In feeding 5 to 20 pounds of soy-bean silage one hour after milking, it was noted that when the quantity fed reached 10 pounds, a slight flavor resulted. This was increased in degree as the quantity of silage given the cows was increased.

Aeration greatly reduced the objectionable flavor, although the extent of the reduction is not shown in the table. When the quantity fed after milking was again reduced to 10 pounds, a slight feed odor was noted by the judges after aeration.

TABLE 12.—*Effect of feeding 5 to 20 pounds of soy-bean silage once daily one hour after milking.*

Result of sampling.	Milk from cows fed silage.	Milk from cows not fed silage.
Number of examinations	16	16
Off flavor	12	0
No off flavor	4	16
Off odor	12	0
No off odor	4	16

Again it is shown that the cows not receiving soy-bean silage, standing in alternate stalls, produced milk not affected by the barn air.

From the experiments with soy-bean silage it is apparent that when this feed is fed one hour before milking, even in such small amounts as 5 pounds per cow, it affects the flavor and odor of the milk. Increasing the quantity fed increased the feed flavor. It is

evident that the proper way to feed this silage is after milking and, further, that even when so fed in quantities from 5 to 20 pounds at a feeding, most of the milk produced has a strong soy-bean silage flavor and odor.

DISCUSSION OF LEGUME-SILAGE EXPERIMENTS.

The legume silages fed in this work were unusually dark in color and had rank characteristic odors. The experiments show that they should be fed only after milking and then in quantities of not more than 15 pounds to a feed if milk reasonably free from feed taints is to be obtained.

Henry and Morrison (*5*) report that, "as a class, the legumes have proved disappointing for silage when ensiled alone." They state further (*4*) that while alfalfa has been ensiled with entire success, "often poor, vile-smelling silage is produced." In regard to soy-bean silage, Woll and Humphrey (*11*) went so far as to say that satisfactory dairy products could not be made when cows were fed this silage. Woodward and McNulty (*12*) report that silage made from clover, while palatable, has an objectionable odor necessitating care in feeding to avoid tainting the milk.

PART PLAYED BY AERATION IN REDUCING SILAGE FLAVORS AND ODORS.

Silage is a palatable, wholesome feed for milking cows, the feeding of which is generally conducive to economical milk production, and it will continue to be fed on an increasing number of dairy farms as its feeding value becomes more generally recognized. Legumes likewise will continue to be grown and fed in increasing amounts for much the same reason. Efforts will be made to save the crop by ensiling just so long as wet seasons prevent its being cured into hay, or when early frosts threaten its growth. In accordance with the method of feeding practiced by busy dairymen, corn and legume silages will continue to be fed both before and after milking. Thus cows that eat pasture weeds, such as garlic and ragweed, or are fed silage, cabbage, or turnips before milking will continue to give tainted milk. The milk from cows kept during certain seasons of the year in unventilated, sometimes unclean, barns will continue to be tainted. These feeding and barn conditions are still more general than they should be, and, until they are corrected, the milk should be taken from the stable as soon as drawn and aeration more generally employed in removing immediately as much of these taints as possible while the milk is still warm. The experiments have shown that this can be done easily and with beneficial results.

The process consists in bringing milk in thin streams into contact with the air, thus permitting the escape of the volatile taint-bearing

substances. As ordinarily practiced, aeration has a double purpose—first, to air the milk; and second, to lower its temperature. Russell (*10*) reports "the method certainly has no disadvantages." It should be borne in mind also that feed and barn taints once removed are removed permanently by the process. Marshall says (*9*) "it is best accomplished immediately after milking." According to Ernst (*2*), "the aeration of milk permits the escape of carbonic acid, hydrogen, and sulphid of hydrogen, and supplies the milk with air so that in all probability the development of certain bacteria is checked, which otherwise, if the milk had been filled in containers in a warm and unaerated condition, would have imparted to the milk a sharp disagreeable taste and odor; the milk would have been 'smothered.'"

PLACE TO USE THE AERATOR.

In aerating milk it should be borne in mind that the same conditions which favor the escape of odors which the milk contains when drawn from the cow are also conditions which permit the milk to become tainted with odors from the outside. For this reason, aeration should take place in a milk room in which the air is free from bad taints or dust, and which is well ventilated.

GOOD FLAVORS AND ODORS IN MILK.

It is important that milk have a good flavor and a good odor. It is probable that some flavors and odors constantly present in milk in time cease to be objectionable to the individual and are taken as a matter of course. In some alfalfa sections of the United States the so-called alfalfa taste is general in milk and in these sections is accepted without comment.

The work has shown that fine-flavored milk is an individual characteristic of some cows. It may be that whole herds of cows giving milk of desirable flavor will be assembled in the future, and the effort made to fix and perpetuate this desirable characteristic by breeding and selection.

Preventive measures are always best; therefore dairymen should endeavor, first, to have cows and barns clean; second, to have cow stables properly ventilated; third, to feed after milking those materials likely to taint milk; and fourth, to decrease feed and barn taints by proper and immediate aeration. Finally, prompt cooling and storing of milk at a low temperature will retard the development of odors from bacterial action.

As stated before, the cows used in these experiments produced daily approximately 10 pounds of milk each. It is possible that with cows of greater or less production different amounts of silage might be fed with varying results as regards intensity of the flavor imparted

to milk. It is believed, however, that the conclusions state fundamentals which will have equal importance under all conditions.

CONCLUSIONS.

There is a wide variation in the flavor and odor of the milk from individual normal cows receiving the same feeds.

While silage-tainted barn air may have some effect on the flavor and odor of milk, it is of relatively small importance under average and even under extreme conditions.

The flavor and odor of silage are largely imparted to milk through the body of the cow.

Silage which is fed one hour before milking is so quickly absorbed that its taint is discernible in the milk.

Silage should be fed immediately after milking.

Not over 15 to 25 pounds of corn silage or 15 pounds of legume silage can be fed twice daily after milking without imparting a discernible flavor and odor to the milk of cows of similar productive capacity to those used in this experiment.

Legume silage affects the flavor and odor of milk to a greater extent than an equal amount of corn silage.

Careful and prompt aeration of the warm milk will permanently remove silage flavors and odors from slightly tainted milk and will reduce the degree of more pronounced silage flavors and odors.

Moderate quantities of corn silage fed after milking and the milk promptly aerated may in some cases actually improve the flavor of milk that would otherwise have a flat or insipid taste.

While silage odors in the barn air have only a slight effect on the flavor and odor of milk, it is best to provide adequate ventilation and exercise other sanitary measures to insure the finest possible flavors.

The feeding of badly decomposed or moldy silage imparts to milk undesirable flavors.

Cream from silage-tainted milk possesses and retains silage flavors and odors to a greater extent than the milk from which it is taken.

Condensed milk made from silage-tainted milk has a less perceptible silage flavor and odor than the milk from which it is made.

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IMPOUNDING WATER IN A BAYOU TO CONTROL BREEDING OF MALARIA MOSQUITOES.

By D. L. Van Dine,[1]

Entomologist, Investigations of Insects Affecting the Health of Man, Bureau of Entomology.

CONTENTS.

INTRODUCTION.

Malaria is responsible for important losses in returns from agricultural crops in the Delta region of the lower Mississippi Valley. The disease is, as well, a great handicap to the further development and extension of agriculture in that region. The prevailing system of labor in the Delta is that of the negro tenant farmer, and it is among this class that the disease is highly prevalent, causing losses

[1] Resigned May 15, 1922. The writer wishes to acknowledge his indebtedness to George S. Yerger, owner of Hecla plantation, for his interest and cooperation in the work; to Alexander Clark, manager of Hecla plantation, for the supervision of the work of clearing the bayou and the construction of the cross levee and spillway of the dam; to Haw Kirkpatrick for the photographic work in connection with the project; to Dr. R. E. Coker, Dr. A. F. Shira, and F. M. Barnes of the U. S. Bureau of Fisheries for the cooperative work on fishes; to the U. S. Bureau of Plant Industry for the plant determinations; to the U. S. Geological Survey for the topographical maps of the region; and to H. H. Kimball, A. H. Jennings, E. Foster, and F. H. O'Neill, formerly of this bureau, for assistance in the survey work.

in time and in reduced efficiency of the plantation hands during the season of the year when the crops are most in need of attention.

The bayous or streams of the region are an important source of the Anopheles mosquitoes which convey malaria, and since the higher ridges offered by the bayou banks are the logical locations for the plantation roadways, the homes of the tenants are located along these banks. While control of the breeding of Anopheles in a bayou is but one factor in the ultimate control of the malaria mosquitoes in the Delta, it is an important factor, for these bayous offer a near-by source of Anopheles in locations on the plantations which are otherwise favorable in respect to distance from breeding areas of these mosquitoes.

Since the general topography of the Delta and the slight fall in the bed of the bayous do not permit drainage, the common practice in disposal of surplus surface water, it became necessary to devise some method of control, practical from the standpoint of plantation management, to prevent breeding of Anopheles in bayous. The Bureau of Entomology has demonstrated that the breeding of Anopheles mosquitoes can be controlled in a bayou by clearing the vegetation and impounding the water. The work was located on Hecla plantation at Mound, Madison Parish, northeastern Louisiana. This bulletin deals with the natural conditions of the bayou before the work was done and with the changed conditions brought about by the work, especially with reference to the breeding of mosquitoes. It also discusses the impounding of water in a bayou from the standpoint of plantation economy.

TOPOGRAPHY AND FORMATION OF THE REGION.

To gain an idea of the relation of the streams of this region to the surrounding topography, it is necessary to discuss in a very general manner the formation of the region. The soil is an alluvial deposit of considerable depth and the formation is characteristic of delta accumulations. There is a slight fall in the general direction of the main stream, the Mississippi River. This river in times past has followed an irregular, winding course through the Delta of its lower valley, often forming new channels. The old channels are marked by the ridges which are peculiar to the region. The bayous, or streams, of the region are in reality old spillways of the river when at flood, formed before the days of the protective levee system by the tendency of the river at stages of high water to break through its built-up banks and form new channels for the surplus water. Before the levees were built, the river and these bayous overflowed their banks at regular seasonal intervals. The heavier particles carried by the water in suspension were deposited first and in larger quantity. The finer particles were deposited in smaller amounts as one

proceeds from the banks of these streams to either side. The deposits from these overflows account for the ridges along the bayous and the ancient channels of the river. There is, therefore, a gradual fall from these ridges to the lands that lie on either side. These lower lands are extensive swamp areas in the basins of which are found permanent swamp "lakes" which are extremely shallow. The banks of the bayous are formed with a steep declivity toward their channels in contrast to the gradual slope toward the swamp areas that lie parallel to them. The region is further characterized by narrow, crescent-shaped lakes within well-defined banks of the old beds of the river, known as "ox-bows" or "cut-offs," formed where the action of the river has cut a new channel through the neck of one of its many horseshoe bends. The ends of these "cut-off" lakes are usually shallow, showing marshlike conditions, but the main body of water is open and comparatively deep. The bayous are not connected with these lakes except during periods of high water. The swamp lakes tend to drain into the bayous at points lower down in the courses of these streams.

FAVORABLE CONDITIONS FOR MOSQUITO DEVELOPMENT.

The swamp areas and the channels of the bayous are attended by a rank growth of vegetation consequent upon the fertile nature of the alluvial deposit and the prevalent moisture which, with the resulting sediment and vegetable débris, promotes an ideal environment for the development of certain species of mosquitoes under favorable climatic conditions. The situation becomes increasingly emphasized by reason of the imperfect drainage due to the slight fall of the land. Among the mosquitoes, Anopheles are found to thrive, and the disease which they convey is prevalent among the inhabitants of the region.

LOCATION OF CULTIVATED LANDS, ROADWAYS, AND DWELLINGS.

In the Delta the timbered lands are practically synonymous with the swamp areas. The open lands, or lands under cultivation, are confined to comparatively narrow strips along the ridges that form the banks of the river, the bayous, and the old courses of these streams. These lands are known as the "front" lands and from the nature of their deposits are sandy in character. The lands lying toward the swamp areas are known as the "back" lands and are a heavy clay, impervious to water, called "buckshot."

The roadways of the region follow the higher lands and, wherever practical, are carried along the bayou banks. The open land is cultivated under the negro tenant system, each tenant living upon the land assigned to him for cultivation. It is therefore logical to find the homes of the tenants on a roadway along the bayou where

one of these streams bounds or sections a property. The houses thus located are in the higher and more open portions of the plantation and usually at maximum distance from the timbered and swamp areas on either side. It is evident that such location of the habitations is favorable in respect to distance from the breeding areas of Anopheles mosquitoes, with the exception of those mosquitoes that originate in the bayou itself.

PROBLEM OF ANOPHELES CONTROL IN THE REGION.

Of course complete drainage of surface water is the logical method of Anopheles control where that method applies, but in the absence of a drainage outlet, and in the presence of surface water favorable for Anopheles breeding throughout the season, other means must be given local consideration. In any consideration of drainage in the Delta it is necessary to note that the streams of this region flow away from the river, that the slope of the land is from the bayou bank toward the swamp areas on either side, and that the fall in the bed of the bayou averages less than a foot to the mile. Under these conditions the question of drainage involves an extensive area; it is not a matter which the plantation owners can consider individually.

The idea of impounding water to suppress mosquito breeding is rather foreign to the general conception of the effect of impounded water upon mosquito production. The relation which impounded water will bear to mosquito production depends altogether upon the conditions under which the work is done and the changes brought about in comparison to the natural conditions. In the question of impounding water in a bayou we must consider the natural character of such a stream and the relation of the stream to the roadways of the plantation and the habitations of the people who cultivate the land. The bayou bank is the logical location for the houses of the tenants and it is important to control the breeding of Anopheles in this nearby source. The bayou under natural conditions favors mosquito production but under impounded conditions does not. The change in conditions is brought about by the preliminary clearing and by the provision for a permanent water level sufficiently high to suppress the growth of aquatic vegetation. Following these operations, the maintenance of a clean margin is all important.

BAYOU WALNUT AND THE ANOPHELES SURVEY.

The work of the Bureau of Entomology was done in a section of Bayou Walnut which quarters the southwest portion of Hecla plantation. This bayou runs a very irregular course from a point slightly north of Milikens Bend on the Mississippi River to Bayou Roundaway, joining the latter stream southwest of Tallulah. From the

View along channel, Bayou Walnut, natural conditions, showing overhanging vegetation. Note log and "floatage" on surface of water.

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FIG. 1.—View along channel, Bayou Walnut, natural conditions, showing overhanging vegetation and aquatic vegetation in bed. Surface of water in foreground covered with duckweed (*Lemna* spp.) and with aquatic plant, *Jussiaea diffusa*, in background.

FIG. 2.—View across Bayou Walnut, natural conditions, showing absence of overhanging vegetation, with aquatic grass, *Zizaniopsis miliacea*, in bed.

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point of origin of the bayou to its junction with Roundaway, the distance in an air line is only 7½ miles. The bayou, however, travels a distance of over 31 miles. The section of Bayou Walnut in its course through Hecla plantation is shown in Figure 1. The average fall of the bayou in this section is 0.6 foot to the mile.

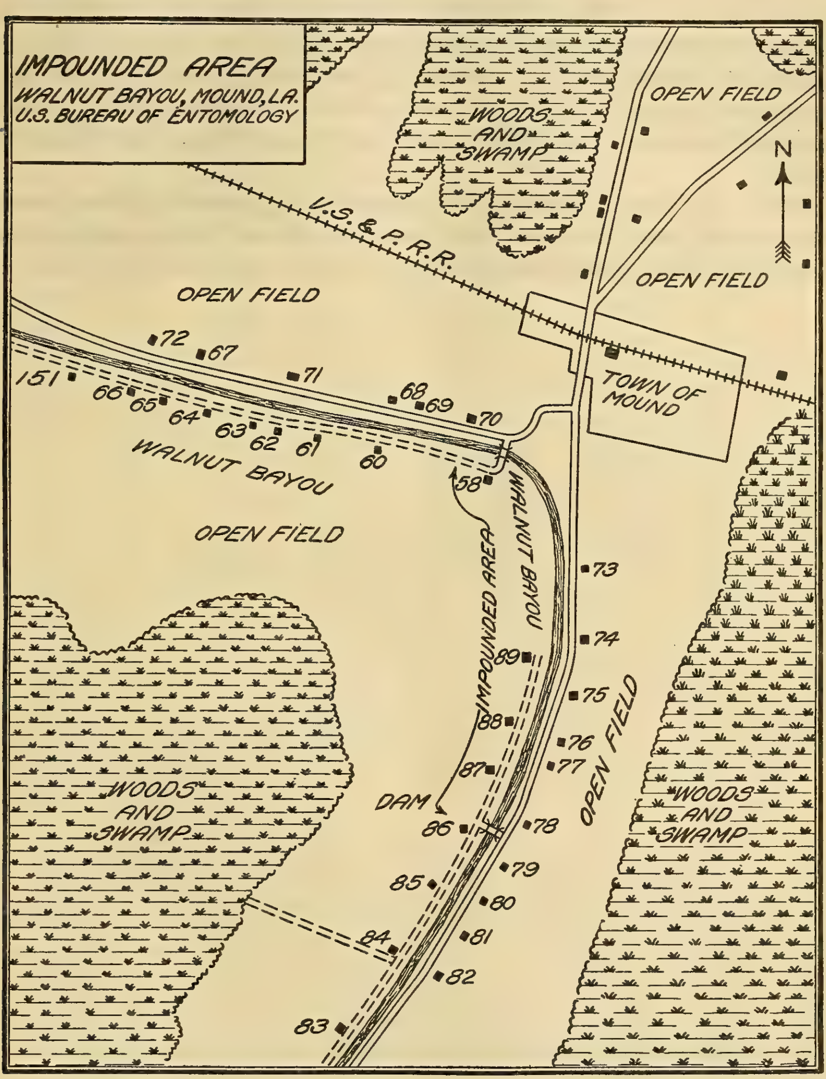

FIG. 1.—Map of section of Bayou Walnut near Mound, La., showing impounded area and surroundings.

During 1914 it was observed that under natural conditions there was practically no breeding of Anopheles in certain restricted sections of the bayou where open water occurred, where the bed was free of vegetation, and where the margins were clean. On the other

hand, breeding was found in those portions of the bayou where the margins were grass-grown or supported a growth of overhanging trees and vines; where the water surface was covered with the resulting vegetable débris or floatage; where the water was shallow enough to support the growth of aquatic vegetation in the bed of the stream; where the channel was blocked by trees, logs, stumps, and brush; or where the bed was partially dry, permitting the summer rains to maintain isolated pools in natural depressions, in hoofprints of animals, and in mud cracks. A comparison of these conditions in the natural bayou is shown in Plates I and II and Plate III, Figures 1 and 2.

The collections of Anopheles larvæ in the general survey work during the years 1914 and 1915 gave, for Bayou Walnut within the limits of Hecla plantation, the records which are shown in Table 1.

TABLE 1.—*Collections of Anopheles larvæ, Bayou Walnut, Mound, La., 1914–15.*

Date.	Record No.	Locality.	Water.		Vegetation.	Character of location.	Amount of Shade.	Gambusia present.	Species.
			Depth.	Temp.					
1914.			*Inches.*	°*F.*					
Aug. 10	4258	H74–75	1–5	104	Weeds	Margin	Open	Common	Species undetermined.
10	4259	H76	5	84	Grass	Channel	Shade	do	Do.
11	4266	H77	5	89			Part shade	do	Quadrimaculatus.
22	4323	H73	3	90–94	Smartweed	Margin	do	Abundant	Quadrimaculatus, punctipennis.
1915.									
May 26	4701	H89			Grass	Channel	Shade	do	Crucians.
June 3	4712	Below dam			Duckweed	Margin	Open	Common	Quadrimaculatus.
8	4724	Station 9			Grass	Channel	Shade	Abundant	Do.
8	4725	do			do	Margin	do	do	Species undetermined.
9	4727	Station 15				do	Open	Common	Quadrimaculatus.
11	4729	do				do	do	do	Species undetermined.
July 6	4748	Station 4	3	90	Willow stump	do	do	do	Quadrimaculatus.
Aug. 3	4772	Station 2				Depression at margin	Shade		Do.
4	4774	Station 3		83		Hoofprints at margin	Open		Species undetermined.
5	4775	Station 4		84		do	do		Do.
5	4776	Station 5	2	88	Willow	Margin	Shade	Common	Do.
6	4783	Station 12		81–85		Hoofprints in channel	Open		Do.
6	4784	Station 13		80–90		Mud cracks in channel	do		Do.
18	4783–10	Station 12		81		Hoofprints in channel	do		Quadrimaculatus.
27	7306	H85			Duckweed			Common	Do.
28	7311	do			do			do	Do.
Sept. 1	7315	Station 10						do	Do.
[1] 8	7318	H85			Duckweed		Shade	do	Do.
Oct. 23	7355	Station 6				Hoofprints in channel	Open		Punctipennis.
27	7358	H79	2			Depression at margin	do		Do.
27	7357	Dam station				Hoofprints in channel	do		Do.
27	7359	Station 3				Mud cracks in channel	do		Quadrimaculatus, punctipennis.
29	7360	do				do	do		Do.

[1] The collections after this date were made after the bayou was cleared but before the rains caused the water to back up over the cleared arca by reason of the dam.

These records indicate general breeding of Anopheles throughout the course of the stream under natural conditions. *Anopheles quadrimaculatus* Say is the common species taken, and *Anopheles punctipennis* Say is second in numbers. It is noted that one collection of *Anopheles crucians* Wied. was made. The undetermined collections represent the Anopheles larvæ which were collected but which were not reared to the adult stage.

For convenience of the survey, the section of the bayou to be cleared of all vegetation was divided into stations 100 yards in length. The distance covered in the experiment was 1,600 yards, nearly a mile. The plants collected from this section, before clearing, during July and August, 1915, are shown in Table 2. The plants listed in Table 2 are distributed according to their location and the depth of water in the bayou in Table 3. The plant determinations were made by the Bureau of Plant Industry of this department. The natural conditions in the bayou, including the vegetation, water levels, and other features, are shown in Plate III, Figure 3; Plate IV; and Plate V, Figure 1.

TABLE 2.—*Plants from Bayou Walnut, Mound, La., 1915.*

Species.	Common name.	Location.
Spirogyra sp	Algæ	Submerged.
Lemna valdiviana, Lemna gibba, Spirodela polyrhiza, and Wolffia columbiana	Duckweed	Floating on water.
Jussiaea diffusa	Primrose-willow	In water, roots in bed.
Zizaniopsis miliacea	Aquatic grass	Do.
Cephalanthus occidentalis	Buttonbush	In channel and along margin.
Salix nigra	Swamp willow	Along margin, overhanging.
Bignonia radicans	Trumpet creeper	Do.
Brunnichia cirrhosa	Buckwheat vine	Do.
Persicaria opelousana	Smartweed	Along margin.
Phytolacca americana	Pokeberry	Do.
Panicum colonum	Ditch grass	Do.
Asclepias perennis	Milkweed	Do.
Ampelopsis arborea	Peppervine	Do.
Belonging to family Euphorbiaceae	Spurge	Do.

TABLE 3.—*Vegetation and depth of water in Bayou Walnut, Mound, La., before impounding, July–August, 1915.*

Station.	Vegetation.			Depth of water in channel.
	Species.	Common name.	Location.	
Dam.	Lemna spp[1]	Duckweed	Floating on water	6 inches to 11 inches.
	Jussiaea diffusa	Primrose-willow	In water	
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Margin, overhanging	
	Persicaria opelousana	Smartweed	Margin	
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
	Euphorbiaceae	Spurge	Margin	

[1] The species of duckweed recorded under *Lemna* spp. in this list represent *Lemna valdiviana*, *L. gibba*, *Spirodela polyrhiza*, and *Wolffia columbiana*. Submerged algæ (Spirogyra) were common along the margins in some locations, but the submerged hornwort (Ceratophyllum) was not collected in this survey, though it is common in some other locations in the region.

FIG. 1.—View along edge of Bayou Walnut, natural conditions, showing open water in channel with grass-grown margin.

FIG. 2.—View along channel of Bayou Walnut, natural conditions, showing clean margin on opposite bank and vegetation along margin in immediate foreground.

FIG. 3.—Looking across Bayou Walnut, 200 yards above site of dam, before clearing.

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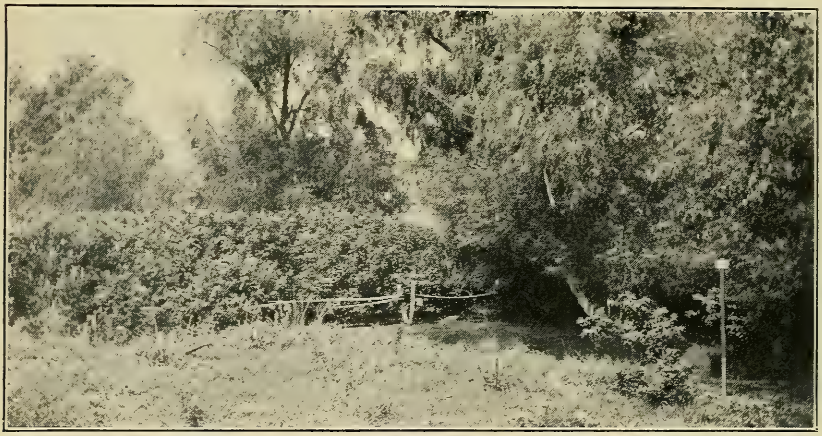

FIG. 1.—Looking down channel of Bayou Walnut, 300 yards above site of dam, before clearing.

FIG. 2.—Looking across Bayou Walnut, 500 yards above site of dam, before clearing.

FIG. 3.—Looking across Bayou Walnut, 900 yards above site of dam, before clearing.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

TABLE 3.—*Vegetation and depth of water in Bayou Walnut, Mound, La., before impounding, July–August, 1915*—Continued.

Station.	Vegetation.			Depth of water in channel.
	Species.	Common name.	Location.	
1	Lemna spp	Duckweed	Floating on water	3 inches to 1 foot 3 inches.
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Margin, overhanging	
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
	Asclepias perennis	Milkweed	Margin	
	Phytolacca americana	Pokeberry	do	
	Brunnichia cirrhosa	Buckwheat vine	Margin, overhanging	
	Persicaria opelousana	Smartweed	Margin	
	Ampelopsis arbroea	Peppervine	do	
	Bignonia radicans	Trumpet-creeper	Margin, overhanging	
2	Lemna spp	Duckweed	Floating on water	3 inches to 1 foot.
	Jussiaea diffusa	Primrose-willow	In water	
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Margin, overhanging	
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
	Asclepias perennis	Milkweed	Margin	
	Phytolacca americana	Pokeberry	do	
	Brunnichia cirrhosa	Buckwheat vine	Margin, overhanging	
	Persicaria opelousana	Smartweed	Margin	
	Bignonia radicans	Trumpet-creeper	Margin, overhanging	
3	Lemna spp	Duckweed	Floating on water	2 inches to 1 foot.
	Jussiaea diffusa	Primrose-willow	In water	
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Margin, overhanging	
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
	Panicum colonum	Ditch grass	Margin	
	Persicaria opelousana	Smartweed	do	
	Asclepias perennis	Milkweed	do	
4	Lemna spp	Duckweed	Floating on water	9 inches.
	Jussiaea diffusa	Primrose-willow	In water	
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Margin, overhanging	
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
5	Lemna spp	Duckweed	Floating on water	2 inches to 6 inches
	Jussiaea diffusa	Primrose-willow	In water	
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Margin, overhanging	
	Zizaniopsis miliacaea	Aquatic grass	Bed, in water	
6	Lemna spp	Duckweed	Floating on water	6 inches.
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Margin, overhanging	
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
7	Lemna spp	Duckweed	Floating on water	2 inches to 8 inches (one-third dry).
	Salix nigra	Swamp willow	Margin, overhanging	
	Zizaniopsis miliacea	Aquatic grass	Bed and margin	
8	Lemna spp	Duckweed	Floating on water	4 inches (two-thirds dry).
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Stumps at margin	
	Zizaniopsis miliacea	Aquatic grass	Bed and margin	
9	Lemna spp	Duckweed	Floating on water	3 inches.
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Stumps along margin	
	Zizaniopsis miliacea	Aquatic grass	Bed and margin	
10	Lemna spp	Duckweed	Floating on water	6 inches.
	Cephalanthus occidentalis.	Buttonbush	Bed and margin	
	Salix nigra	Swamp willow	Stumps along margin	
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
11	Salix nigra	Swamp willow	Margin	2 inches (one-third dry).
	Zizaniopsis miliacea	Aquatic grass	Bed, in water	
12	Salix nigra	Swamp willow	Trees in bed, stumps along margin.	Dry (except hoof-prints and mud cracks).
13	Salix nigra	do	do	Do.
14	Salix nigra	do	do	Dry, except small pool near bridge.
	Zizaniopsis miliacea	Aquatic grass	Margin	
15	Salix nigra	Swamp willow	Stumps along margin	Dry, except one small pool.

FISHES OF THE REGION.

A survey of the fishes of this region was made by the United States Bureau of Fisheries in cooperation with this work. This survey was intended to cover the distribution of the top minnow (*Gambusia affinis*) in this region; the possible presence of fishes other than this minnow that would be useful in mosquito destruction; the fishes valuable as food in the deeper and permanent areas of water; the survival of Gambusia in the impounded area in Bayou Walnut; and the possibility of establishing in the impounded area fishes that would be of value for food to the tenants on the plantation. This work was accomplished during 1916 and the early part of 1917. The fishes collected in Bayou Walnut under natural conditions are listed in Table 4. It is seen that *Gambusia affinis* is the prevalent species.

TABLE 4.—*List of fishes taken in five collections in the natural area, Bayou Walnut, Mound, La., 1916–17.*

Species.	Common name.	Number of collections.	Number of specimens.
Gambusia affinis	Top minnow	5	124
Dorosoma cepedianum	Hickory shad	1	20
Lepomis cyanellus	Green sunfish	1	20
Lepomis humilis	Sunfish	1	19
Lepomis pallidus	Blue-gill sunfish	1	4
Lepomis symmetricus	Sunfish	1	3
Pomoxis sp.		1	3
Carpiodes sp.		1	1

A point of special interest in connection with the natural conditions of the bayou is the fact that Gambusia is found in connection with general breeding of Anopheles. The breeding of these mosquitoes in the presence of comparatively large numbers of this minnow is accounted for by the protection afforded the mosquito larvæ by the aquatic and marginal vegetation and the vegetable débris upon the surface of the water. Further, the partially dry condition of the bayou at certain seasons provides isolated pools and water in hoofprints of animals and in mud cracks from rains, to which the fish do not have access.

A complete list of the fishes collected in this region, not including the impounded area in Bayou Walnut and the Mississippi River, is shown in Table 5.

TABLE 5.—*List of fishes taken in 38 collections from seasonal and permanent waters (exclusive of Mississippi River) in the vicinity of Mound, La., 1916–1917, by F. M. Barnes, United States Bureau of Fisheries.*

Species.	Common name.	Number of collections.	Number of specimens.
Gambusia affinis	Top minnow	27	2,410
Lepomis cyanellus	Green sunfish	16	151
Lepomis humilis	Sunfish	10	126
Lepomis megalotis	Sunfish	4	6
Lepomis pallidus	Blue-gill sunfish	3	9
Lepomis symmetricus	Sunfish	2	4
Lepomis ischyrus	Sunfish	1	1
Lepomis euryorus	Sunfish	2	13
Dorosoma cepedianum	Hickory shad	12	483
Notemigonus crysoleucas	Roach, shiner	11	582
Ameiurus nebulosus	Common bullhead	11	198
Ameiurus melas	Black bullhead	1	1
Pomoxis annularis	Crappie	10	836
Pomoxis sparoides	Calico bass	9	104
Chaenobryttus gulosus	Warmouth bass, "goggle-eye"	5	35
Signalosa atchafalayae	Shad	5	313
Aphredoderus sayanus	Pirate perch	4	20
Roccus chrysops	White bass	4	4
Hybopsis hyostomus (sp. ?)		4	20
Micropterus salmoides	Large-mouth black bass, "trout"	3	5
Micropterus dolomieu		2	4
Hiodon alosoides	Shad	3	21
Hiodon tergisus		1	22
Aplodinotus grunniens	Fresh water drum, "gaspergou"	3	6
Centrarchus macropterus	Round sunfish	2	60
Ictiobus cyprinella	Common buffalo	2	14
Ictiobus bubalus	Small-mouth buffalo	1	1
Percina caprodes	Log perch	2	2
Amia calva	Bowfin, "grinnel"	2	4
Lepisosteus tristoechus	Alligator-gar	2	6
Labidesthes sicculus	Skipjack	2	5
Stizostedion vitreum		2	5
Elassoma zonatum	Pigmy sunfish	1	75
Fundulus chrysotus	Killifish	1	8
Ictalurus furcatus	Blue cat	1	4
Carpiodes thompsoni		2	2
Carpiodes velifer		2	73
Eupomotis (sp. ?)		1	1
Serranidae (gen. ?, sp. ?)		1	1

A comparison between the numbers of Gambusia in the natural bayou and in all other classes of water shows an average of 25 specimens for each collection in the bayou and an average of 63 per collection for all other places. These figures indicate that these little fish are very abundant and very generally distributed in the region. The larger average per collection for all classes of water, as compared with the natural bayou, is explained by the fact that certain collections were made at the season of low stages of water which found these fish highly concentrated in some locations.

CLEARING THE BAYOU.

The clearing of the bayou was done during August, 1915. It was accomplished then for the reasons that the water in the stream was at its lowest level and that the plantation had finished its cultivation of the crops but had not as yet begun to harvest. This plan gave minimum water conditions and a supply of labor for the work without interference with the plantation operations. The smaller under-

growth was removed first, piled along the banks, and burned when sufficiently dry. The trees, logs, and stumps were then removed and placed upon the banks in suitable lengths for hauling away for use as firewood. In many instances the roots of the larger trees and old snags could not be removed without an amount of effort which would have added greatly to the cost of the work. These were sawed off even with the bed of the bayou and allowed to remain. They might have been removed rather cheaply by the use of dynamite, had the facilities for that work been available. The photographs represented by Plate III, Figure 3; Plate IV; and Plate V, Figure 1, give a very good idea of the extent and nature of the work that was done. The appearance of the stream during the operation of clearing is shown in Plate V, Figures 2 and 3.

CONSTRUCTION OF THE DAM.

In making the fill, or cross levee, for the dam, advantage was taken of a shallow point in the bed of the bayou used as a low-water crossing by the tenants. The banks at this point were favorable—that is, high enough on either side to allow the water to be raised to the required level. The required height of water was gained by running levels along the banks above the site of the dam. The dam was constructed to give a depth of 4 feet 10 inches at the floor of the spillway. When one recalls that the fall in the bed of the bayou in this section averages only 0.6 foot to the mile, it is seen that the level at the dam was carried back over the course of the stream for a considerable distance with only a slight variation in depth. The impounding was effective for depth about ½ mile above the zone included in the survey, with the exception of a ridge which crosses the bed of the bayou just above the last station.

The details of the fill and spillway for the dam are shown in Figure 2 and in Plate VI, Figures 1 and 2. The completed dam, with bridge over the spillway, providing a roadway to the section of the plantation lying on the opposite side of the bayou, is shown in Plate VI, Figure 3. The labor and material involved in clearing the bayou and in the construction of the fill and spillway for the dam, are shown in Table 6. The bill of lumber for the spillway is shown in Figure 2.

TABLE 6.—*Cost of clearing a section of Bayou Walnut and impounding water in same, 1915.*

Preliminary survey, running levels, plan and specifications of spillway		$45.00
Clearing undergrowth and grass from bed and edges of bayou, including piling and burning:		
15 men, 6 days, at $1.25	$112.50	
3 men, 5 days, at $1	15.00	
		127.50

FIG. 1.—Looking up channel of Bayou Walnut, 1,500 yards above site of dam, before clearing.

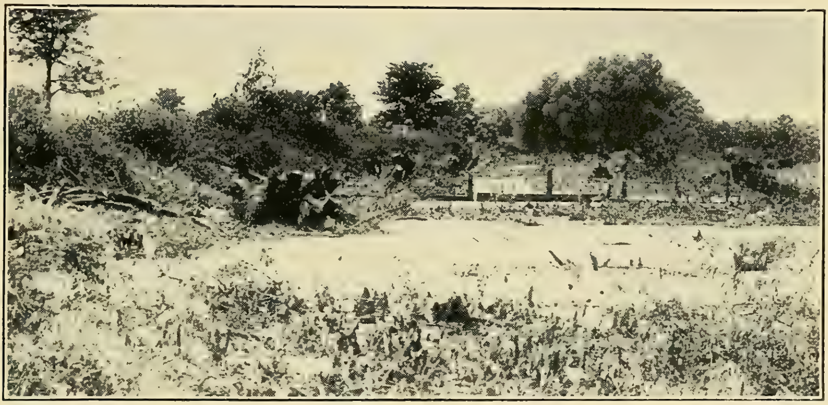

FIG. 2.—Looking up channel of Bayou Walnut during the work of clearing, from point 300 yards above site of dam.

FIG. 3.—Looking up channel of Bayou Walnut from site of dam, after channel has been cleared and undergrowth piled along banks.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

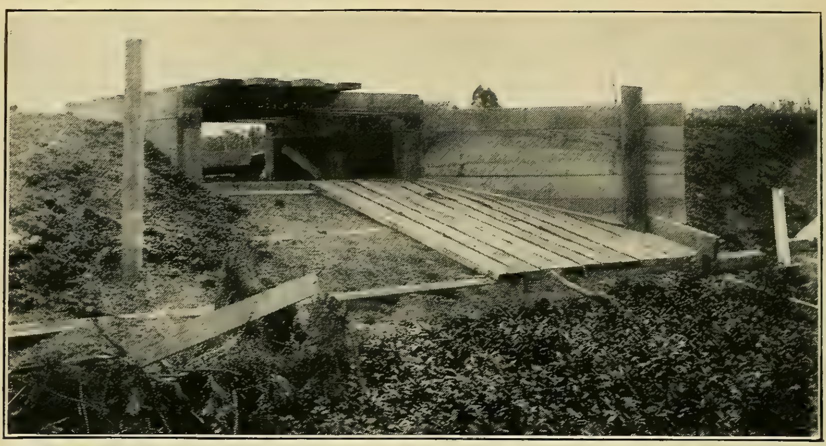

FIG. 1.—View showing construction of spillway-box and downstream apron in dam.

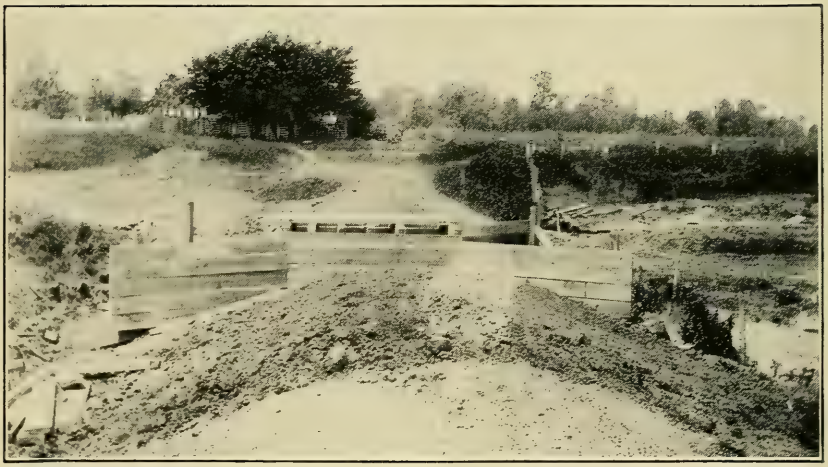

FIG. 2.—View across Bayou Walnut showing wing walls of spillway and bridge over spillway box.

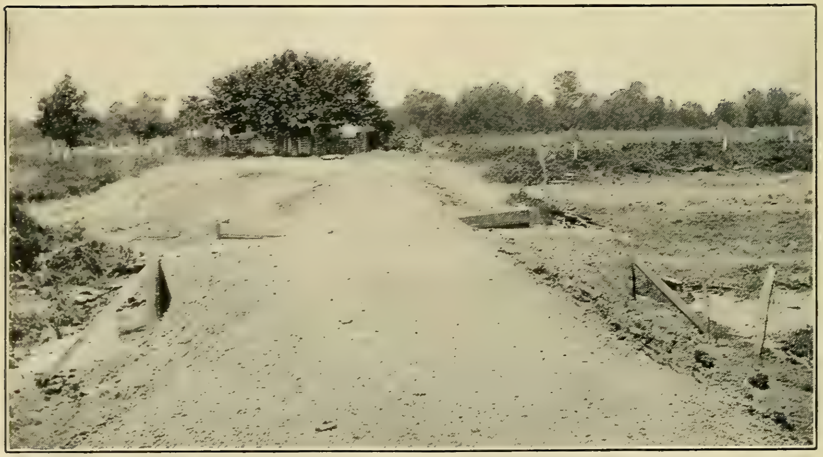

FIG. 3.—View across Bayou Walnut at site of dam, showing roadway to opposite side of bayou.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

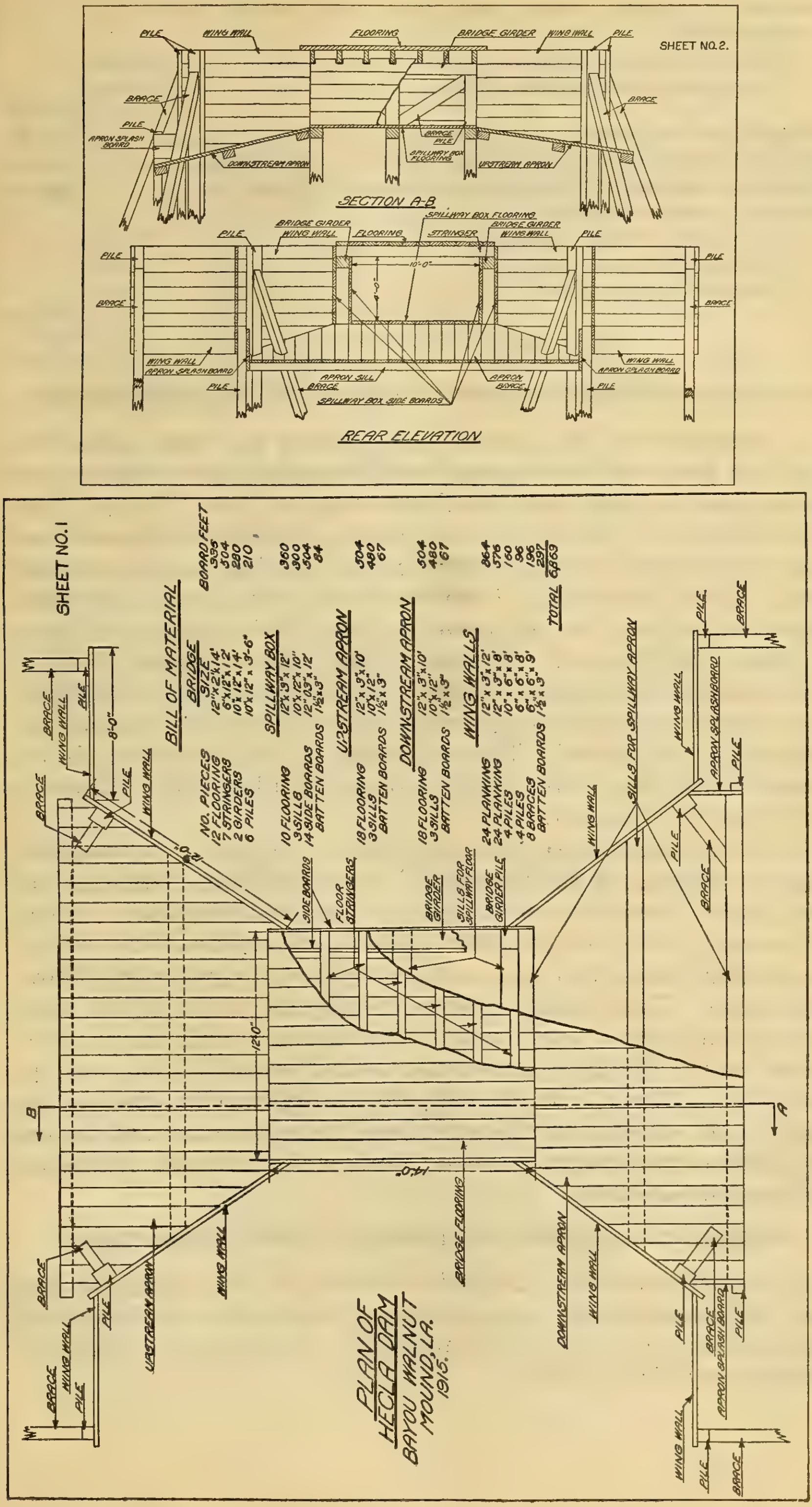

FIG. 2.—Plan of Hecla Dam, Bayou Walnut, Mound, La., 1915.

Removal of trees and stumps and cutting into suitable lengths for hauling away:		
16 men, 8 days, at $1.25	$160.00	
1 team and driver, 4 days, at $3	12.00	
		$172.00
Raking edges and burning trash, 4 men, 6 days, at $1		24.00
Fill or cross levee at dam, 6 teams and drivers, 5 days, at $3		90.00
Lumber for spillway, 7,000 square feet cypress, at $18 per M		126.00
Carpenter work on spillway:		
1 carpenter, 6 days, at $2.25	13.50	
1 helper, 6 days, at $1.50	9.00	
2 helpers, 2 days, at $1	4.00	
		26.50
Total		$611.00

MAINTENANCE WORK FOLLOWING CLEARING AND CONSTRUCTION.

A comparison of the cleared bayou, before the water backed up over the bed, with the natural conditions that have already been shown, may be made from the illustrations in Plate VII and Plate VIII, Figure 1. These views were taken after the undergrowth had been burned and the wood from the trees and logs had been hauled away. Later in the year, at the onset of the winter rains, the water began backing over the bed above the dam. This condition is shown in Plate VIII, Figure 2. It is noted that quite an amount of débris was floated to the surface. As the water level was raised, this floating material collected along the margins, and this was cleaned out with rakes and burned. The appearance of the bayou later in the season, when filled with water, is shown in Plate VIII, Figure 3, and Plate IX, Figure 1.

The only maintenance work, in so far as vegetation is concerned, was the clearing of the " floatage " along the banks following the first rise of water and cutting back a comparatively small amount of second growth, mostly grass (*Zizaniopsis miliacea*) and willow shoots that found their way to the surface of the water the following spring. These shoots were removed by the use of a boat and a curved knife on a long handle. Maintenance work has been required on the dam by reason of the work of crawfish, *Cambarus* sp., about the spillway, and this difficulty, as well as the effect of the work of the crawfish on the water level above the dam, and in turn the effect of the change in water level on the marginal vegetation, will be discussed later.

SURVEY OF ANOPHELES BREEDING AFTER IMPOUNDING.

A comparison of the Anopheles breeding in the impounded area and in the natural bayou is shown by the collections in the general survey work for the years 1916 and 1917. The records for these collections are listed in Table 7.

TABLE 7.—*Collections of Anopheles larvæ, Bayou Walnut, Mound, La., 1916–17.*

Date.	Record No.	Locality.	Water.		Vegetation.	Character of location.	Amount of Shade.	Gambusia present.	Species.
			Depth.	Temp.					
			Inches.	*°F.*					
1916.									
July 26	194	H84			Jussiaea	Channel	Shade	Very abundant	Quadrimaculatus.
Aug. 2	201	H151			Spirogyra	Margin	Open	Common	Do.
2	201	H151			Bushes and floatage.	Channel	Shade	do	Do.
8	205	H151			Spirogyra	Margin	Open	do	Do.
8	205	H151		86	Grass and floatage.	Channel	Part shade	do	Do.
8	205	H153	36	86	Willow	do	Shade	do	Do.
1917.									
June 11	1683	300 yards below dam	3–10	76	Shrubs	Margin	do	do	Do.
11	1684	do	8	77	do	do	Part shade	do	Do.
11	1685	U. S. B. F. Station 2	12	88	do	do	Open	do	Do.
26	1699	U. S. B. F. Station 1	6	77	do	do	Part shade	do	Species undetermined.
26	1700	do	6	77	Duckweed	do	Open	do	Quadrimaculatus.
July 5	1904	U. S. B. F Station 5		94	Grass	do	Part shade	do	Do.
14	B17	H153	6–12	79	Willow and floatage.	do	Shade	do	Do.
14	B18	U. S. B. F. Station 2		91	Duckweed	do	Open	Abundant	Species undetermined.
23	B23	H153	15–18	90	Floatage	Channel	Shade	Common	Quadrimaculatus.
26	B33	U. S. B. F. Station 1		96	Duckweed	Margin	Open	do	Do.
26	B34	H153	15–18	88	Willow	do	Shade	do	Species undetermined.
Au . 1	B37	U. S. B. F. Station 1	6–8	86	Buttonbush and willow.	do	do	do	Quadrimaculatus.
3	B40	H153	15	81	Willow	Channel	do	do	Do.
9	B44	H153	9	84	do	do	do	Abundant	Species undetermined.
11	B47	U. S. B. F. Station 1	6–8	79	Duckweed	do	do	do	Do.

It is seen that the collections are confined to the sections of the bayou below the dam and to the backwater above the impounded zone. No specimens were taken in the collections in the impounded area proper. The section of the bayou above the impounded area was clear for a distance of about ½ mile and the backwater gave favorable conditions for nonbreeding in this distance with the exception of a limited area just above the last station where a ridge crosses the bed of the bayou and where the aquatic grass (*Zizaniopsis miliacea*) persisted, as shown in Plate IX, Figure 2. The maximum depth where this grass survived was about 1 foot. Below this point to the dam, a distance of nearly a mile, an average depth of 3½ feet was maintained which was sufficient to suppress this grass as well as all other vegetation in the channel. Another location of Anopheles breeding found above the impounded zone was some distance above the growth of grass mentioned, among willows and other vegetation characteristic of natural bayou conditions. This location is shown in Plate IX, Figure 3.

FISHES IN THE IMPOUNDED AREA.

A survey of the fishes in the impounded area in Bayou Walnut, the results of which are given in Table 8, shows that the top minnow (*Gambusia affinis*) finds no difficulty in establishing itself under the conditions of deeper and open water. The fish collections in this water also show that the larger fishes of the region, those of value for food, have found their way to the impounded area in some numbers. The more valuable of these for food are the crappie or "white-perch" (*Pomoxis annularis*), the calico bass (*Pomoxis sparoides*), the large-mouth black-bass or "trout" (*Micropterus salmoides*), and the warmouth bass or "goggle-eye" (*Chaenobryttus gulosus*). These game fishes are largely predacious and of course take their toll from the Gambusia, but this feeding of these larger fishes upon the little top minnows must not be viewed so much in the light of the reduction of the mosquito-eating minnows as from the standpoint that the patrol work which they do serves to keep the little fishes in the shallow water along the margins. In the open water of the impounded area there is no mosquito breeding and since the salvation of the little fishes depends upon their remaining along the margin to escape the larger fishes, the value of the larger fishes as an indirect aid in mosquito control is seen.

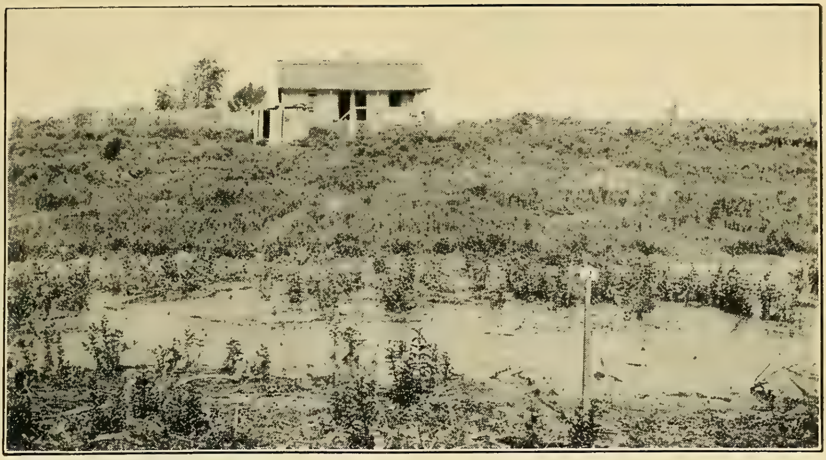

FIG. 1.—View across Bayou Walnut, after clearing, 200 yards above site of dam. Compare with Plate III, Figure 3.

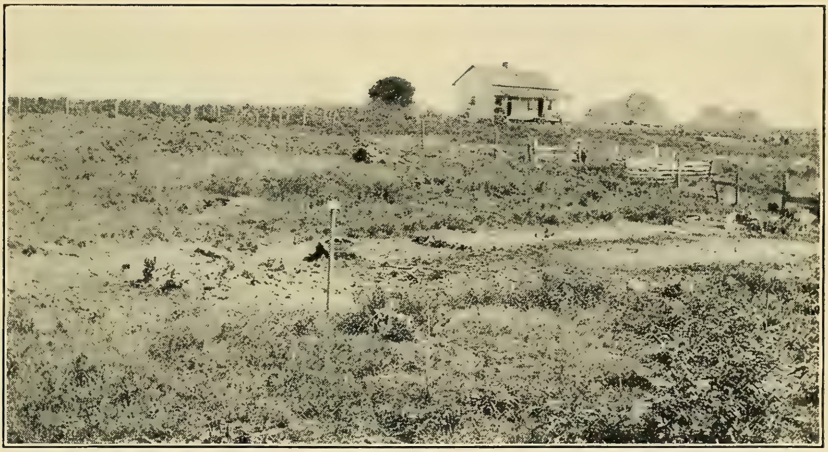

FIG. 2.—View across Bayou Walnut, after clearing, 300 yards above site of dam. Compare with Plate IV, Figure 1.

FIG. 3.—View across Bayou Walnut, after clearing, 800 yards above site of dam.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

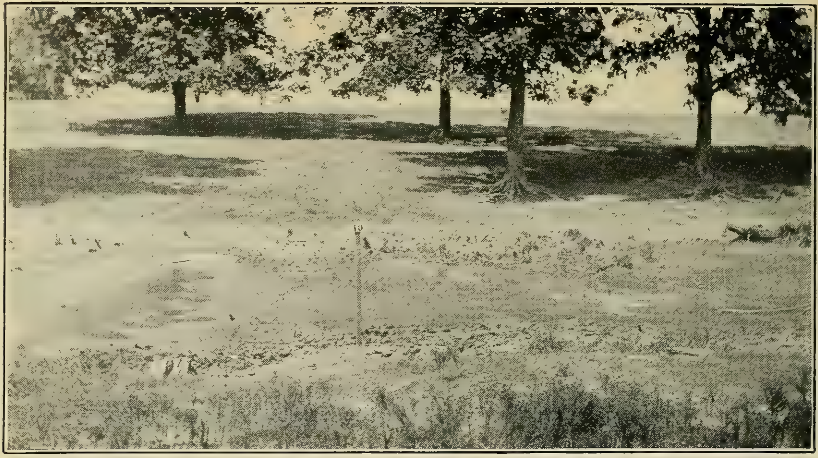

FIG. 1.—View across Bayou Walnut, after clearing, 1,000 yards above site of dam.

FIG. 2.—Looking up channel of Bayou Walnut, after first rise of water, from point 300 yards above site of dam. Note "floatage" along margin. Compare with Plate IV, Figure 1, and Plate V, Figure 2.

FIG. 3.—View above dam, Bayou Walnut, with bayou filled with water. Compare with Plate V, Figure 3.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

FIG. 1.—View toward dam and spillway, Bayou Walnut, from upstream, showing bayou filled with water.

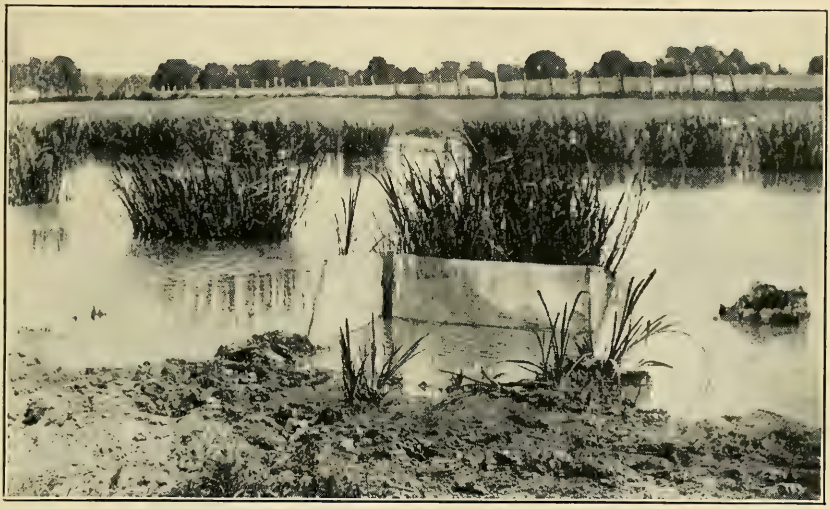

FIG. 2.—View across Bayou Walnut, showing aquatic grass, *Zizaniopsis miliacea*, in bed of bayou, above impounded zone.

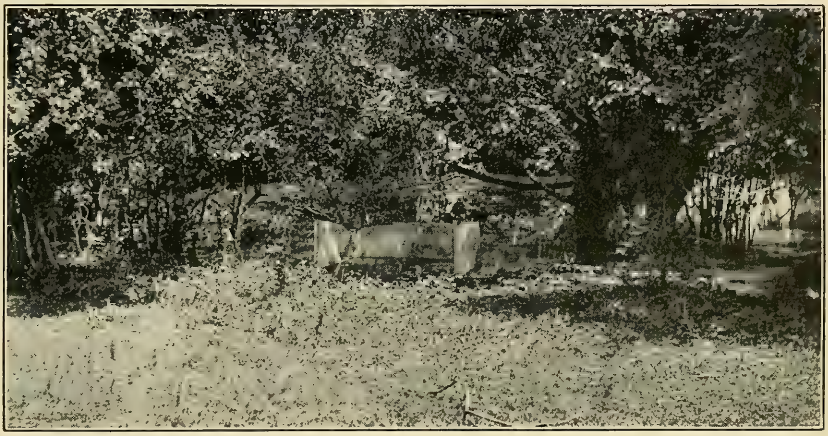

FIG. 3.—View along margin of Bayou Walnut, above impounded zone, showing natural bayou conditions.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

TABLE 8.—*List of fishes taken in 12 collections in the impounded area, Bayou Walnut, Mound, La., 1916–17, by F. M. Barnes, U. S. Bureau of Fisheries.*

Species.	Common name.	Number of collections.	Number of specimens.
Gambusia affinis	Top minnow	7	163
Lepomis cyanellus	Green sunfish	7	95
Lepomis humilis	Sunfish	6	89
Lepomis pallidus	Blue-gill sunfish	1	1
Lepomis ischyrus	Sunfish	1	1
Lepomis symmetricus	do	1	1
Lepomis megalotis	do	1	1
Pomoxis annularis	Crappie	5	103
Pomoxis sparoides	Calico bass	3	25
Ameiurus nebulosus	Common bullhead	5	43
Dorosoma cepedianum	Hickory shad	5	15
Notemigonus crysoleucas	Roach, shiner	3	151
Aphredoderus sayanus	Pirate perch	2	3
Micropterus salmoides	Large-mouth black bass	2	2
Micropterus dolomieu		1	3
Chaenobryttus gulosus	Warmouth bass, "goggle-eye"	1	12

In the comparison of the numbers of the top minnows found per collection in the natural bayou and in all other classes of surface water it was seen that for all classes of water there was an average of 63 Gambusia per collection and for the natural bayou 25 specimens per collection. From the figures in Table 8 we find an average of 14 specimens of Gambusia for the 12 collections made in the impounded water. Just as the comparison of the numbers of these fish in the natural bayou and in all other classes of water is influenced by the fact that some of the collections in the latter case were made in locations where the fishes were highly concentrated, so in the impounded water, as compared with the natural bayou, we must consider the effect of great dilution in the former. It is sufficient for the practical results of the work to note that the Gambusia survived in important numbers the effects of the impounding, and that the presence of the game fishes in the area serves the purpose of keeping the top minnows along the margins where they are useful in the marginal control of mosquito breeding.

FACTORS PREVENTING MOSQUITO BREEDING IN THE IMPOUNDED WATER.

The nonbreeding of Anopheles in the impounded water is due to a number of factors which have not as yet been definitely measured. In general, as has been stated, the important difference between the impounded section of the bayou and the natural bayou is just the difference between lakelike conditions which do not favor the development of Anopheles and swamplike conditions which do favor such development. The factors which are considered to operate against mosquito development are the greater freedom for action on the part of the predators, the fish and the aquatic insects; wave action; depth, which influences temperature of the water; absence

of the vegetable shelter, which operates against the concentration of adults along the bayou and consequent oviposition; and depletion of the larval food of Anopheles furnished by the decaying vegetation and the low forms of aquatic life, both plant and animal, common to the swamplike conditions of the natural bayou.

LEAKAGES CAUSED BY CRAWFISH AND MEANS OF PREVENTING THEM.

The work of maintenance at the dam due to the action of crawfish about the boxing of the spillway has been mentioned. The crawfish burrowed through the fill below the level of the water above the dam to the lower side of the fill. The action of the water through these openings in carrying away the dirt caused serious leakage, which resulted in a decidedly lower level of water above the dam. In several instances the level of the bayou was lowered materially before proper repairs in the dam were made. This damage was not serious the first year following the completion of the dam, but during the following years, up to 1920, considerable expense was involved in preventing the leakage in the dam due to the work of the crawfish. In 1920, a double course of sheet piling with overlapping joints was driven below the fill, leaving an opening for the spillway, the boxing of which was carried through and over the sheet piling. This served to prevent the crawfish from working to the outside, below the fill, and to hold the water above the dam at a permanent level.

An important biological observation was made in connection with the variable water level caused by the leakage in the dam due to the crawfish. It was found that when the water was lowered, after remaining at one level for a period, the water found a clean edge free from débris and grass and, further, that the drying out above the new level served to destroy the aquatic and semiaquatic vegetation that had gained a foothold. Then when the leakage had been repaired and the water level raised to its original height, it rested against comparatively clean margins. The growth of marginal vegetation was thus discouraged by this variable water level, and this explains the lack of any maintenance work on control of marginal vegetation in the impounded area. Thus, the expense in the maintenance work on the dam was offset in part by the saving in the work on the margins.

The experience with the crawfish suggests two improvements to be considered in any further work on impounding water in a bayou in this region. The first is the prevention of injury to the fill in the dam on the part of crawfish. This can be accomplished by a core wall extending below and to each side of the spillway box in the center of the fill. The second is provision for controlling the water level above the dam. The object of this is to make use of the effect

of a variable water level on marginal vegetation and marginal breeding. This is obtained by a change in the water level from time to time. This can be accomplished by a sluiceway through the fill below the level of the floor of the spillway. The flow of water through the sluiceway can be controlled by a gate. If the sluiceway is placed at the level of the bed of the bayou, in the center of the fill, it will act efficiently in lowering or raising the water level above the dam, and, also, the current of water through the sluiceway at this point will flush out and carry away the mud and sediment that tend to accumulate in the bed immediately back of the fill.

ADVANTAGES OF IMPOUNDING, APART FROM PREVENTION OF ANOPHELES BREEDING.

A special advantage to the plantation, apart from the control of Anopheles breeding in the bayou, is the fact that the impounded water gives an ample supply of good water for the live stock throughout the dry summer season. The land lying between the roadway and the bed of the bayou is ordinarily used for pasture purposes by the tenants living along the stream. Except in some instances where clearing has been done in a comparatively wide strip of land found between the road and the channel of the bayou, the pasture along the stream is limited in extent and the grasses are crowded out by weeds, bushes, trees, and vines. During the seasons of dry weather the water in the natural bayou is shallow and stagnant. The supply is often difficult of access by reason of the tangle of overhanging and aquatic vegetation. The animals often become bogged in seeking the water, and the more shallow and isolated pools are converted into wallows, particularly where hogs are pastured along the bayou side. The situation under these conditions is unsightly and insanitary and the supply of water is limited in amount and of the poorest quality. With the limited pasturage the animals do not thrive, and often die. The pasture for the plantation stock—that not owned by the tenants—is the wet land lying between the cultivated areas and the timber and swamp. These pasture lands extend into the timber and the live stock depend upon the swamps and the shallow lakes in the basins of same for water. In any prolonged dry season this supply becomes greatly restricted and as objectionable in quality as that in the bayou. When this situation becomes acute it is necessary for the plantation to drive wells throughout the pasture areas and pump water. This adds greatly to the expense of taking care of the stock. On Hecla plantation, following the clearing of the section in Bayou Walnut and impounding the water, the management not only extended the fencing to include the entire impounded area, but also arranged the fencing of the pastures in one section of the plantation so that by a system of gates the live stock

from the regular pastures could visit the impounded water. The impounding was effective for depth, in so far as an abundant and good water supply is concerned, for a distance of nearly 2 miles and thus furnished water for all of the stock of the tenants living along the stream and for the larger portion of the plantation live stock during the dry seasons as well. The clearing served to increase the amount of available pasture, particularly of value to the tenants for their cows and work animals, and the feeding of these animals along the impounded water aided in the suppression of the marginal vegetation. The management of the plantation has stated that the advantage of a permanent supply of good water for the live stock would alone justify the expense of the clearing and the impounding project.

The owners of Hecla plantation are also operating a lumber mill at Mound. Before impounding the water in Bayou Walnut, the source of water for the boilers at the mill was a driven well. This water proved undesirable for boiler purposes by reason of the salts which were precipitated in the generation of steam. This caused some expense and considerable loss in time at the mill. A pipe line was laid from the bayou to the mill and the impounded water pumped to same for boiler purposes. The management of the mill has stated that the saving in the mill expenses would more than justify an annual expense equal to the cost of the project. In fact, the mill management contributed very largely the funds for maintenance at the dam made necessary by the injury from the crawfish.

A further advantage is gained in that the impounded water offers a source of fish for food. The bass, or "trout," and the crappie, or "white perch," are now present in some numbers. The "buffalo" (*Ictiobus cyprinella*) has been caught occasionally and will no doubt increase in numbers, and the sunfish (*Lepomis* spp.), or "bream," are common. The tenants are able to do a considerable amount of line fishing and every catch adds to the supply for their tables, furnishing a valuable food and a saving in meat.

An advantage not to be overlooked is the great improvement in the property which adds to its value. The further value of the impounded area of the bayou as a place of recreation for the tenants is a very practical point in plantation economy which should be given consideration.

SUMMARY.

The bayous, or streams, of the Delta region flow away from the river, their banks are higher than the surrounding lands, and the fall in their beds is very slight. The shallowness of water in these streams, with prevalent aquatic and overhanging vegetation, favors the development of Anopheles mosquitoes. The peculiar relation

of these streams to the surrounding topography does not permit drainage. In the absence of a drainage outlet, the Bureau of Entomology conceived the idea of clearing a section of one of the bayous and impounding the water to note the effect of a change from the swamplike conditions of the natural bayou to the lakelike conditions of the impounded area, on the capacity of the bayou for Anopheles production.

It is important to control breeding of Anopheles in bayous for the reason that these streams offer a near-by source of mosquitoes, since the houses on a plantation in the Delta are located on the roadways along the bayou banks, where one of these streams sections or bounds a property.

A section of Bayou Walnut at Mound, La., was cleared of all vegetation and the water in this area impounded by means of a cross-levee, or fill, and spillway. This served to keep the water over the bed of the stream above the dam at a sufficient height to suppress the further growth of vegetation.

It was found by comparative studies that this clearing and impounding was effective in preventing the breeding of Anopheles in the bayou where formerly such breeding was common.

Cooperative work on the part of the United States Bureau of Fisheries demonstrated that the mosquito-eating top minnow (*Gambusia affinis*) is generally distributed in the region, but that under natural delta conditions this minnow is found coincident with prevalent breeding of Anopheles. It was also demonstrated that this minnow has established itself in important numbers along the margins of the impounded area. One of the important factors in the natural control found to exist in the impounded water is believed to be the greater freedom for action which the condition of an open surface of water gives to these fish and to aquatic predacious insects. The fish are noneffective in control under natural conditions by reason of the protection afforded the mosquito larvæ by the aquatic and marginal vegetation and the vegetable débris upon the surface of the water. Other factors in the natural control in the impounded zone are considered to be wave action, influence of a greater depth on breeding, absence of shelter for adults along the course and consequent reduction of oviposition, and the depletion of the food of Anopheles larvæ.

The important points to be considered in impounding water in a bayou for mosquito control are the preliminary clearing of all vegetation, the provision for a permanent level of water sufficiently high to suppress the further growth of aquatic and semiaquatic vegetation, and the maintenance of a clean margin.

A further point in the construction of the dam is provision to prevent the work of crawfish, which, otherwise, work through the fill and cause serious leakage. The water level in the project under dis-

cussion varied greatly at times, due to failure to make such provision. However, from this variable level which occurred, the experience was gained that such fluctuation in level operated as an aid in the control of the marginal vegetation which otherwise would have gained a foothold and would have required an expenditure for the maintenance of clean margins. The suggestions are made that the crawfish injury can be prevented by a core wall through the center of the fill to either side and below the box of the spillway in the dam, and that a variable water level can be secured by a sluiceway, with control gate, through the fill and core wall.

Advantages to the plantation from the impounding work, apart from the control of Anopheles breeding, are a permanent supply of good water for live stock during the dry season; an extension of the land available for pasture; the deeper and more extensive water of the impounded area, which offers a favorable place for game fish and thus furnishes a source of food; and the lake-like body of water which offers recreation to the plantation people and adds to the attractiveness and value of the property.

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BULLETIN No. 1099

Washington, D. C. ▼ August, 1922

FROST INJURY TO TOMATOES.[1]

By R. B. Harvey, formerly *Plant Physiologist, Office of Plant Physiological and Fermentation Investigations*, and R. C. Wright, *Physiologist, Office of Horticultural and Pomological Investigations, Bureau of Plant Industry.*

CONTENTS.

INTRODUCTION.

The importance of our tomato industry and the fact that a large part of the crop is shipped and handled during the winter and early spring months make the knowledge of the freezing temperatures of tomatoes of considerable economic importance to growers, shippers, and handlers of this crop.

Some idea of the scope of the tomato industry in the United States may be obtained from the following statistics compiled by the Bureau of Markets of the United States Department of Agriculture. Farmers' Bulletin 1233, "Tomatoes for Canning and Manufacturing," contains some additional data on the importance of the industry (*1*)[2]. During the year 1919 approximately 14,469 cars of tomatoes were shipped to all markets. In 1918 the number of cars was 15,458; in 1917 there were 13,910 cars; and in 1916 14,749, making a 4-year average of 14,646 cars. The States which ship field-grown tomatoes to the early market are Florida, Mississippi, Texas, and California, and they furnished 8,184 cars, or 56 per cent, of this yearly average. The total production and value of the crop of tomatoes for shipping from these four principal States in 1919 are shown in Table 1.

[1] This bulletin presents the results of a portion of the work carried on in the Bureau of Plant Industry under the project "Factors Affecting the Storage Life of Vegetables."

[2] The serial numbers (italic) in parentheses refer to "Literature cited," at the end of this bulletin.

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TABLE 1.—*Production and value of tomatoes shipped from the principal shipping States in 1919, according to statistics prepared by the Bureau of Markets.*

State.	Production.	
	Tons.	Value.
Florida	58,520	$9,714,320
Mississippi	18,400	1,692,800
Texas	17,700	1,628,400
California	17,380	729,960
Total	112,000	13,765,480

The heaviest of these car-lot shipments are made during the months of March, April, May, and June, although in Florida shipments in car lots begin in December. Smaller quantities of tomatoes are also shipped from Mexico, Cuba, and the Bahamas. These very early grown fruits supply the holiday markets in the large cities and represent a comparatively high money value. Michigan, Colorado, Iowa, New Jersey, and Virginia also produce large quantities of tomatoes, but their crops are grown chiefly for local consumption and canning. Their period of production extends from about June until the vines are killed by frost in the fall. (Table 2.)

TABLE 2.—*Statistics compiled by the Bureau of Crop Estimates and the National Canners' Association on tomatoes used in the United States for manufacturing and canning in 1918, 1919, and 1920.*

Items of comparison.	1918	1919	1920
Area grown...acres..	317,102	195,645	244,745
Yield...tons..	1,323,059	724,912	1,003,358
Cases (each containing 24 No. 3 cans)	15,882,372	10,809,660	11,368,000

Somewhat over half of our tomato crop, then, exclusive of canning tomatoes, is grown in the South and Southwest and shipped to the northern markets in the winter and spring months, when a good part of the product in transit and on the market is in constant danger of freezing. A considerable portion of the crop is usually cut short in the fall by early frosts while most of the vines are still producing vigorously.

Many data covering a period of three years have been accumulated in the Bureau of Plant Industry on the freezing points of a number of varieties of tomatoes, in both green and ripe stages; also data bearing on the freezing of tomatoes in the field. These results are incorporated in this bulletin.

VARIETIES STUDIED AND RESULTS.

Freezing points, or the temperatures at which tomatoes freeze, were determined on authentic varieties grown by the Department of

Agriculture at the Arlington Experimental Farm, near Washington, D. C. The varieties were Bonny Best, Olney Special, Earliana, John Baer, Landreth, Early Michigan, Marvel, Bloomsdale, Red Rock, Trucker's Favorite, New Glory, Stone, Greater Baltimore, Columbia, Delaware Beauty, Livingston's Globe, Livingston's Acme, Sunrise, and Sterling Castle. Since most of the tomatoes are shipped while still green but practically full grown, freezing points in many of the varieties were determined on full-grown green tomatoes as well as ripe ones. These determinations were made by subjecting them to an air temperature of about 15° F. As it had been found by previous tests that no differences in results were obtained by using portions of tomatoes instead of whole fruits and since the work could be carried on more rapidly by using only portions, this method was largely followed. A good representative sample of each fruit was obtained by cutting with a sharp cork borer parallel to a septum between the sections, thus removing a portion of both flesh and pulp. Temperature records were made by the thermoelectric method, using the thermocouples described by Taylor (*4*) with the White potentiometer. In Table 3 are shown the average freezing points of the varieties mentioned, which are arranged in the order of the earliness of the first picking of ripe fruit. Each freezing point given represents the average for a number of different pickings of each variety.

TABLE 3.—*Average freezing points of 19 commercially grown varieties of tomatoes.*

Variety.	Ripe.		Green.		Variety.	Ripe.		Green.	
	Freezing point.	Number of determinations.	Freezing point.	Number of determinations.		Freezing point.	Number of determinations.	Freezing point.	Number of determinations.
	° *F.*		° *F.*			° *F.*		° *F.*	
Bonny Best	30.60	27	30.57	6	Stone	30.31	21	30.15	5
Olney Special	30.59	5			Greater Baltimore	30.62	16		
Earliana	30.52	17	30.24	10	Columbia	30.31	20		
John Baer	30.57	21	30.53	7	Delaware Beauty	30.02	5		
Landreth	30.45	10			Livingston's Globe	30.58	5		
Early Michigan	30.67	20	30.70	11	Livingston's Acme	30.46	14		
Marvel	30.03	10			Greenhouse varieties:				
Bloomsdale	29.99	16			Sunrise	30.58	15	30.29	7
Red Rock	30.55	6	30.58	11	Sterling Castle	30.54	12	30.11	5
Trucker's Favorite	30.06	8							
New Glory	29.78	9			Average	30.46		30.39	

As shown in Table 3 the average freezing point of the 19 varieties was 30.46° F., and the greatest difference in the freezing points of any two varieties was 0.89° F. No consistent difference in results is noticeable between early and late varieties. It is also shown that full-grown green tomatoes in general did not show any significant difference from ripe fruit in their freezing points. The greatest difference was 0.29°, which is of little practical importance.

UNDERCOOLING.

Tomatoes, along with many other fruits and vegetables, may be undercooled to a considerable extent.[3] Briefly, undercooling is the cooling of the tissue, without actual freezing, below the true freezing point. The freezing point is the temperature at which ice crystals begin to form in the tissue, with subsequent injury to the surrounding tissue. Experiments have shown that tomatoes will often remain in this undercooled state for several hours without injury provided they are undisturbed.[4] Six whole Sunrise tomatoes were placed in a temperature of 22° F. In seven hours after passing 32° F. the specimens reached an average maximum undercooled temperature of 22.63° F. Shortly after this, without being disturbed in any way, freezing commenced, and the temperature rose to the actual freezing point of 30.64°, where it remained for several hours. Experience has shown that at any time after the temperature of a tomato goes below its true freezing point, or, in other words, at any time it is undercooled it can be made to freeze by a sudden jar. This fact is of practical importance to growers, and especially to shippers, because if a shipment is known to have been subjected for any length of time to a temperature below the freezing point of tomatoes part or all of the fruit may be undercooled but not frozen provided they have not been disturbed. If the temperature is raised above the freezing point within a limited time, it is possible that the tomatoes will not be frozen. Tomatoes, however, that are subject to a freezing temperature while actually in transit will probably freeze with little or no undercooling, owing to the constant jarring received from the vibration of the car or truck. It is reasonable to assume that in general tomatoes in storage or at rest will undergo a lower temperature without injury than they would in transit.

Other observations were made on the freezing points of whole fruits in an air bath in which the temperature and rate of fall of the temperature could be accurately controlled. Dry tomatoes were placed in the compartment and the temperature lowered gradually in three hours from 50° to 32° F. This allowed the fruits to come to the same temperature irrespective of their size. Water was then sprinkled over them. When the temperature reached 30.9° the water on the surface froze, but the tomatoes did not show frozen spots until an air temperature of 30.3° F. was reached. Usually much greater undercooling occurred with tomatoes with an unbroken skin. The temperature then was maintained at 29° F. Freezing

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[3] See Department of Agriculture Bulletins 895 and 916 for a discussion of undercooling in potatoes (5 and 6).

[4] Actual injury is not necessarily caused by the low temperature, but it directly follows the formation of ice crystals within the cells or intercellular spaces.

always occurred first in the tissue directly beneath each drop of water, and there was no doubt that inoculation of this tissue from contact with ice at these points caused the tissue to freeze. Earliana and Sunnybrook tomatoes showed frozen spots more quickly than the Beauty variety, and the latter froze much quicker than the Trucker's Favorite, Ponderosa, Greater Baltimore, and Stone varieties. Green tomatoes always undercooled less than ripe tomatoes of the same variety, but the difference between the undercooling points of ripe and green tomatoes in the Earliana type is less than in other varieties.

Some tomato varieties have a marked tendency to crack at the stem end. This is especially true of Chalk's Early Jewel, Earliana, New Century, and Sunnybrook Earliana. Such tomatoes undergo scarcely any undercooling and are therefore easily injured. But even when the skin is not visibly broken the Earliana variety does not undercool so much as some other varieties, as, for example, the New Century, which resembles Trucker's Favorite and Livingston's Globe in that it has a tough cuticle (*3*). Hundreds of tomatoes of several varieties were tested, but none were found with freezing points below 29.78° F. A tough skin and no tendency to crack at the stem end are evidently good characters to breed for in order to obtain varieties resistant to freezing.

In those varieties in which the blossom end turns red much before the stem end freezing occurs first at the stem end. The freezing points of the two ends of the tomato were determined by thermocouples. In partly ripened tomatoes tissue from the ripe blossom end showed a freezing-point depression a few tenths of a degree lower than tissue from the green stem end; however, in no case did it amount to as much as 0.4° F. This difference may be due to the formation of sugars in the ripening cells.

EFFECT OF COLD ON THE TOMATO PLANT.

The tomato plant belongs to a class of annuals which show but little adaptation to low temperature and can not be frozen without killing. On exposure to low temperature the plants become somewhat more difficult to freeze—that is, the freezing point is lowered—but as soon as ice formation occurs within the tissues the cells are killed.

During the usual weather conditions which precede the first killing frost in autumn the night temperature is usually somewhat above 32° F. but low enough to increase the accumulation of osmotically active sugars, with a consequent lowering of the freezing point of the plant sap. Attendant also upon the low temperature there may be a stopping of growth, with the formation of a thicker cuticle over the surface of young leaves and fruits. A thickened cuticle is of impor-

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tance in frost resistance, for it allows the tissue beneath it to be undercooled below the freezing point.

As shown in a previous publication (*2*), the freezing-point depression of tomato-plant juice can be increased about 0.2° F. by exposing the plants for five days at 37.4° F. This may be considered an adaptation to low temperature; but it can not be carried far, because certain physiological disturbances occur which will result in the death of the plants although they are not frozen. It is therefore seen to be impossible to harden tomatoes to make them immune to frost, like cabbages and such other biennials and perennials, which can be frozen stiff without injury if they are allowed to adapt themselves to cold during a preliminary hardening period. We have to deal with the factors of undercooling and freezing-point depression in the case of tomatoes rather than with frost immunity.

STUDIES IN THE FIELD.

In experiments on the freezing of tomatoes in the field, a series of temperature measurements was made by means of mercury thermometers of temperature at Bell, Md., on a clear, still night on which the first frost of the autumn of 1919 occurred. The temperature measurements from which the data shown in Figure 1 were obtained were taken in a field in which 26 varieties of tomatoes were under test to determine their relative frost resistance. The field was located on a gentle slope, and down the incline an almost imperceptible stream of cold air flowed.[5] The current of cold air was rather shallow, flowing down hill in a layer only a few feet deep. The coldest part of the current was about 10 inches above the ground. At the ground the lower part of this current seems to have been warmed by radiation from the earth. At 18 inches above the ground the air current was somewhat warmer, owing to the tendency of the denser and colder air to move downward. One can frequently see smoke or mist floating on these denser strata near the ground.

The curves in Figure 1 give the air temperatures at ground level and 6 inches and 18 inches above the surface of the ground as well as the surface and internal temperatures of three tomatoes situated from 10 to 12 inches above ground. These temperatures were determined by thermometers placed at the surface of each tomato or inserted into holes in the fruit made by removing plugs of the same size as the thermometers with a cork borer. From the graphs it is seen that the temperature within the tomato lagged considerably behind that of the air immediately outside. This lag is due to the heat capacity of the tomato and increases with the size of the fruit. With the out-

[5] For a more detailed discussion of temperature relations, see "Frost and the Prevention of Damage by It." (7).

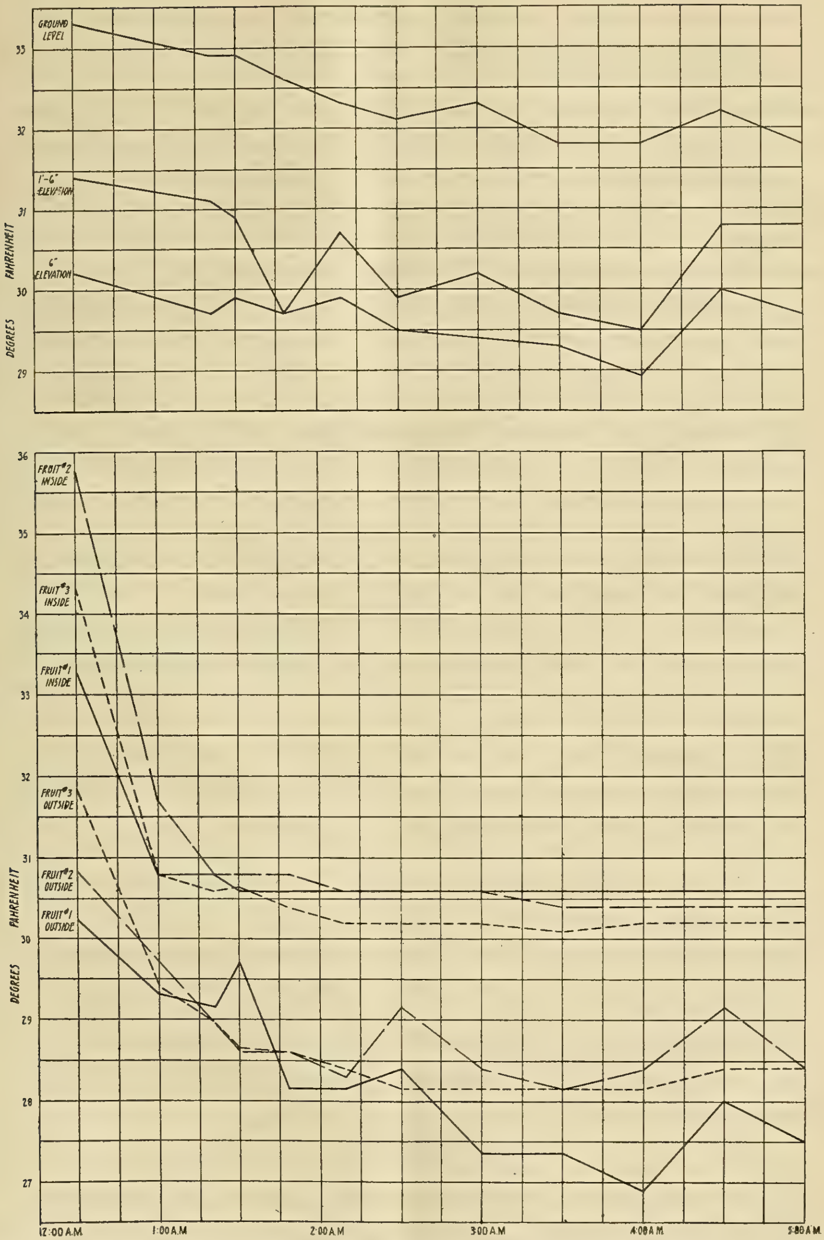

FIG. 1.—Hourly temperature measurements taken at Bell, Md., on the night of the first frost of the autumn of 1919. Thermometers were placed at ground level and at elevations of 6 and 18 inches; also at the surface and centers of three tomatoes on the vine at about 12 inches elevation.

side temperature at 30.2° and falling to 29.5° F., it required about $1\frac{1}{2}$ hours for the temperature of tomato No. 1 to fall from 33.3° to 30.6° F. It is, therefore, possible, on account of this temperature

lag, to have a short duration of temperatures somewhat below freezing without injuring the fruits. During the night considerable dew was deposited in droplets on the upper surface of the tomatoes. The dew began to freeze when the temperature inside of the tomatoes reached 31.1° F. This is scarcely less undercooling than the water on adjacent leaves showed, but dew on the leaves froze a little quicker than that on the fruits because of the radiation of heat from the latter. When the tomatoes had reached 30.6° F., they began to freeze at the surface where the thermometers had been introduced, and dark-colored areas became visible, due to changes in the reflection of light from the frozen tissue. The final freezing points of fruits Nos. 1, 2, and 3 were 30.6°, 30.4°, and 30.2° F., respectively. Owing to the heat liberated by the freezing out of water, the inside temperature of the tomatoes did not fall below 30° at any time, although the outside temperature fell to 26.9° F. In tomatoes which were undisturbed it was observed that freezing did not begin as soon in sound tomatoes as in those in which the skin was broken. It will be noted that no undercooling was recorded. This was probably due to the freezing dew on the surface of the tomatoes. Previous investigations by the Bureau of Plant Industry of freezing injuries to potatoes showed that wet potatoes freeze more readily than dry ones (*6*). Freezing began on young fruits first and on the top side. on which dew had deposited.

No differences could be detected in the freezing points of the plants in 26 varieties in this field. If differences exist it would require carefully equalized temperatures to detect them. The young leaves freeze first, and in these the injury occurs first along the vines. The average freezing point of tomato leaves was found to be 30.22° while stems froze at 29.99° F.

Tomatoes which lie directly upon the ground are warmed by conduction from the warm earth and do not freeze as quickly as those situated up on the vine. When the vines are very leafy those tomatoes which hang on the inner branches are not frozen as soon as exposed fruits, because they are protected from radiating their heat by the surrounding leaves.

SUMMARY.

(1) A large portion of the tomato crop grown in the Southern States and shipped north in the late winter is in constant danger of frost injury while in transit.

(2) The average freezing point of 19 commercial varieties was determined to be 30.46° F.

(3) A difference of 0.89° F. was found between the freezing points of certain varieties of tomatoes.

(4) No consistent difference was found between the freezing points of ripe and practically full-grown green tomatoes of the same varieties.

(5) No consistent difference in freezing points of early and late varieties was found.

(6) Six average tomatoes were undercooled in the laboratory to 22.63° F. before freezing commenced. The freezing point was 30.64 F.

(7) Tomatoes can be undercooled below their freezing point and if undisturbed may remain without freezing for a limited time; however, at any moment while undercooled a slight jar is liable to cause freezing.

(8) The possession of a thick skin with little tendencey to crack is apparently an important factor in the frost resistance of tomatoes. Under field conditions such a covering favors the undercooling of the fruits by preventing inoculation of the tissue from ice formed on the surface.

(9) The freezing point of ripe parts of a tomato may be slightly lower than for green parts of the same fruit. Tomatoes on the vine freeze on the upper stem end first partly for the above reason and partly because dew deposits on the upper side and tends to inoculate the surrounding tissues.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1100

Washington, D. C. ▼ September, 1922

A METHOD OF DETERMINING GREASE AND DIRT IN WOOL.

By D. A. SPENCER, *Senior Animal Husbandman in Sheep and Goat Investigations*, J. I. HARDY,[1] *Sheep Husbandman, and* MARY J. BRANDON, *Scientific Assistant in Sheep and Goat Investigations, Animal Husbandry Division, Bureau of Animal Industry.*

CONTENTS.

OBJECT OF THIS INVESTIGATION.

The object of the wool-scouring investigation here discussed is to afford a fair basis for comparing the grease and dirt indices of various wools, the indices to be used to divide wools into groups for the study of other qualities affected by or associated with grease and dirt contents, such as length of fiber, fineness, density of fleece, spinning quality, strength, and weight of clean wool per fleece. Data obtained are to be used in planning the mating of the sheep that grow the fleeces studied for the purpose of fleece improvement in the qualities mentioned.

METHOD OF OBTAINING DATA.

Sheep-breeding investigations conducted by the Bureau of Animal Industry, United States Department of Agriculture, involve extensive studies in fleece improvement. Individual fleeces of about 2,000 sheep are studied each year, and the problem of obtaining data on the net yield of clean wool from each fleece has prompted the development of a method of single-fleece determination that would yield dependable results without necessitating the complete

[1] Moisture experiments reported in this bulletin were conducted by J. I. Hardy during the winter of 1919 and 1920. Doctor Hardy resigned from the department in February, 1920.

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scouring of all the wool. Separate determinations of the grease and dirt content of each fleece furnish information of great usefulness for sheep-breeding studies in connection with their application to wool improvement, but the expense of separate determinations for so large a number of fleeces creates the necessity for working with samples instead of scouring entire fleeces. A sample weighing approximately 1 pound is therefore taken from the side of each fleece at the time the sheep are sheared. These samples are then sent direct to the Bureau of Animal Industry wool laboratory, near Beltsville, Md., and stored in a dry room until they are used in the

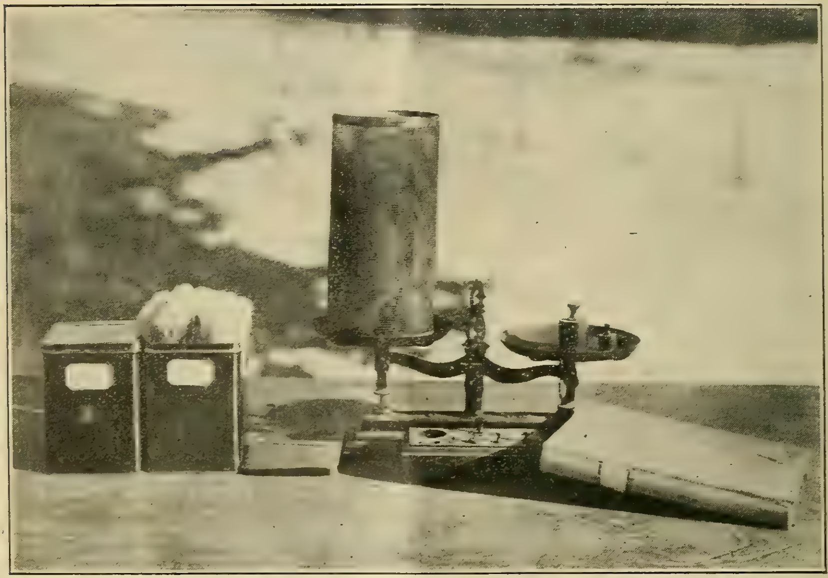

FIG. 1.—Wool containers, balance, and record book. The closed container shows the can of raw wool ready for shipping and storing at the wool laboratory, Beltsville, Md. Upon preparing the wool for scouring, the container is opened and the wool is placed in the basket shown on the balance. A sample sheet of the data kept in the record book is shown in Table 7.

scouring test. Most of the fleeces studied to date have been grown on the bureau's experimental range sheep at the United States sheep experiment station, near Dubois, Idaho, although fleeces grown at the bureau's farm sheep stations near Beltsville, Md., and Middlebury, Vt., are also being sampled for use in this investigation.

EXPERIMENTAL WORK.

INDEX FIGURES FOR GREASE AND DIRT.

Specially designed apparatus has been constructed to remove the grease by the use of gasoline, without loss of dirt, and later in another apparatus the wool is washed to remove all the dirt.

Approximately 250 grams of each sample of wool as it comes from the storage room are used for the scouring test. The sam-

ples are placed in wire-mesh baskets (see Fig. 1) and brought to a constant-moisture content[2] by drying in an oven. After heating at 50° C. for three hours in this conditioning oven they are weighed with a delicate balance. (See Fig. 2.)

The samples are then placed in extraction containers and washed with deodorized gasoline (gas-engine gasoline) such as is used in canning factories. After the gasoline is put on the samples they are agitated up and down in the container 10 times and are allowed to stand for 45 minutes, after which the gasoline is allowed to filter through 13-inch filter papers. After all the gasoline is filtered,

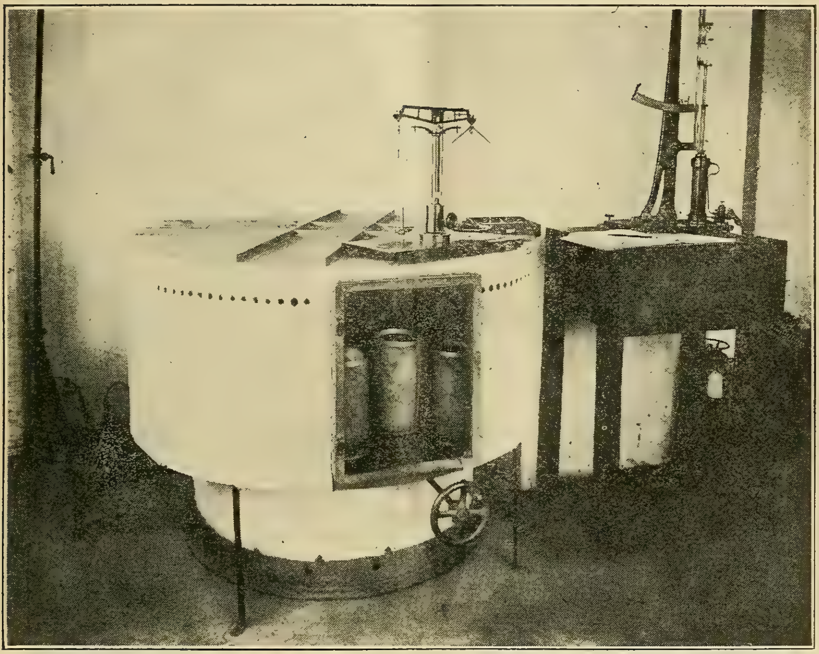

FIG. 2.—Conditioning oven. Note method of weighing wool baskets without opening glass oven door. Baskets are brought into position for weighing by turning the wheel shown below and in front of the oven. When in position the basket is hooked on to the weighing apparatus.

the filter paper containing the dirt is folded and placed with the sample. Clean filter papers are then placed under the extraction containers, and a second gasoline washing is given the wool samples. The same filter papers are used for the second and third extractions. After three gasoline extractions the remaining filter papers are also placed with their respective samples and the wool is again brought to air-dry condition. (See Figs. 3 and 4.) When it is necessary to save time the samples are placed in a blower-dryer to speed up this operation. (See A, Fig. 4, also C, D, and E, Fig. 5.) Drying for one hour in the blower-dryer and standing in the open at room temperature for 15 minutes brings the samples to an air-dry

[2] "Constant-moisture content," as used here, allows for a slight variation but is insufficient to affect the results appreciably.

condition. The samples are again dried, at 50° C. for three hours, and weighed.

The samples are next washed with soap and water at a temperature of from 40° to 45° C. for three-quarters of an hour. (See Fig. 5.) About one-half pound of neutral soap is placed in the first vat containing 150 gallons of water. After washing the samples, the water is squeezed from them and they are placed in a second vat and washed for half an hour in clear water at a temperature of from 40° to 45° C. When washing extremely dirty wool, one-quarter of a pound of neutral soap is added to the 150 gallons of water in the

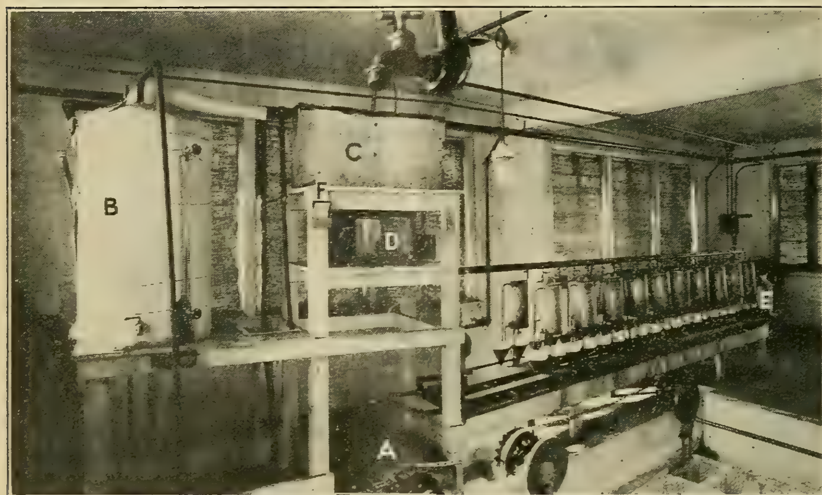

FIG. 3.—Grease extraction apparatus. Extraction containers are shown in the right half of this illustration, with filter papers beneath. The baskets of wool are placed in these containers and gasoline is poured into the containers until within 2 inches of the top Lids are placed on the containers after the agitating process, and the gasoline is allowed to stand 45 minutes. Upon filtering, the gasoline returns to the pressure tank, A. It is then forced into the distillation tank, B, condensed in tank, C, and returned through the collecting tank, D, and the upper pipes into can, E. At F is shown the card file bearing the weekly schedule of work. A card is used for each day's program. This schedule is shown in full on page 17.

second vat and the wool is again washed for 30 minutes, but soap is not used in the second vat unless the wool is extremely dirty. In case soap has been used in the second vat the water is squeezed from the wool and it is washed a third time in clear water at the same temperature. After the samples have been washed in one clear water for 30 minutes the water is squeezed from them by the use of a wringer; they are put into the original containers and dried in the blower-dryer at 60° C. for eight hours, allowed to stand overnight, and conditioned in the conditioning oven for three hours. The weight of the grease is found by the difference in the weight of conditioned, greasy wool and the conditioned weight of the sample after three washings with gasoline. Likewise the weight of the dirt is found by the difference in the weight of the conditioned wool

after washing with gasoline and the weight of the same conditioned wool after washing with soap and water.

BASIS OF THE INDEX FIGURES.

A difference in dirt content of raw wool would cause a difference in the percentage weight of grease and clean wool in samples that

FIG. 4.—Degreased wool airing after three treatments of gasoline. The two large cans in the foreground are shown collecting the gasoline returned from the gasoline still in the rear. Air pipe, A, connects lower and upper parts of blower dryer used for drying wool after washing.

are similar except that one is of lower dirt content than the other. Likewise, a difference in grease content would cause a realignment of percentage figures. In order, therefore, to obtain a fair and constant basis for indices of grease and dirt, the actual weight of each of these materials removed is considered in its relation to the

final weight of clean wool found in the sample. For example, the grease index is calculated by the following formula:

$$\frac{100 \times \text{weight of grease}}{\text{weight of clean wool}}.$$

CONDITIONING FOR WEIGHING.

The foregoing outline shows the need of three weighings of each sample. It often happens that different classes of wools may be handled at the same time and similar wools may be worked with on days varying widely as to temperature and moisture. In order to get useful data from the determinations made throughout the year and with different wools, it is necessary to condition the wools for each weighing in such way as to overcome the effect upon the results of differences in natural moisture or of moisture contents as affected by varying air conditions. Two samples of wool might contain quite different quantities of moisture, due to their contents of grease and foreign matter. The index figures would be based upon final weight of clean wool. This index might be rendered incorrect to the extent of 0.03 per cent in case conditioning was not sufficient to bring these samples to a uniform moisture content, for example:

Sample A under natural conditions in air contains—

	Grams.
Moisture	15
Grease	20
Dirt	40
Clean wool	25
Total weight	100

Sample B has similar amounts of grease and clean wool, but 45 per cent of its weight in dirt and only 10 per cent moisture. The true composition is then as follows:

	Grams.
Moisture	10
Grease	20
Dirt	45
Clean wool	25
Total weight	100

Results of tests shown in Table 2–*c* indicate that imperfect conditioning might remove 60 per cent of the moisture from sample A and only 50 per cent from sample B. Calculation of the grease index on this basis would therefore result as follows:

Sample A, 60 per cent of 15 grams moisture removed equals 9 grams, leaving a remainder of 6 grams.

	Grams.
Moisture	6
Grease	20
Dirt	40
Clean wool	25
Total weight of conditioned sample	91

One hundred grams of such conditioned wool would have:

	Grams.
Moisture	$\frac{100\times 6}{91}=6.59$
Grease	$\frac{100\times 20}{91}=21.98$
Dirt	$\frac{100\times 40}{91}=43.96$
Clean wool	$\frac{100\times 25}{91}=27.47$
Total	100

$$100\times\frac{21.98 \text{ (grams of grease)}}{27.47 \text{ (grams of clean wool)}}=80.01, \text{ grease index.}$$

Sample B, 50 per cent of 10 grams moisture removed equals 5 grams, leaving a remainder of 5 grams.

	Grams.
Moisture	5
Grease	20
Dirt	45
Clean wool	25
Total weight of conditioned wool	95

One hundred grams of such conditioned wool would have—

	Grams.
Moisture	$\frac{100\times 5}{95}=5.26$
Grease	$\frac{100\times 20}{95}=21.05$
Dirt	$\frac{100\times 45}{95}=47.37$
Clean wool	$\frac{100\times 25}{95}=26.32$
Total	100

$$100\times\frac{21.05 \text{ (grams of grease)}}{26.32 \text{ (grams of clean wool)}}=79.98, \text{ grease index.}$$

Even though there is a difference of 5 per cent in the moisture of sample A as compared with sample B, the grease index is not changed appreciably, the difference here shown being $80.01-79.98=0.03$.

Table 1 shows results from nine samples, A-1 to A-9. The air-dry weights of these samples were taken on a comparatively dry day and conditioned for three hours at 50° C. These same samples were exposed in a moist room and again conditioned for three hours at 50° C. They are designated in the table as B-1 to B-9. All weights are given in terms of grams.

TABLE 1.—*Comparison of effects of dry weather and wet weather on conditioning of wool.*

Sample.	A.		B.		Difference between conditioned weights A and B. Per cent based on conditioned "A" samples.	
	Dry-day air weight.	After 3 hours at 50° C.	Wet-day air weight.	After 3 hours at 50° C.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
1	272.5	263.5	284.9	266.2	2.7	1.01
2	272.8	262.0	283.4	263.2	1.2	.45
3	271.1	259.7	282.0	261.6	1.9	.72
4	273.3	262.8	283.9	264.9	2.1	.79
5	274.0	262.3	282.6	261.3	−1.0	−.38
6	303.0	291.1	311.8	291.3	0.2	.06
7	272.0	262.5	282.7	263.5	1.0	.38
8	269.7	259.1	278.5	259.2	0.1	.038
9	277.5	266.0	286.8	266.6	0.6	.22

There is a maximum difference of 2.7 grams, or 1.01 per cent, in the moisture of samples A and B after three hours' conditioning. According to calculations of grease indices for samples A and B, which are shown just preceding Table 1, this difference is not large enough to affect seriously the figures for grease index.

Table 2 shows the results of conditioning wool for different lengths of time and gives comparisons of the effect of conditioning wool at 50° C. as compared with conditioning at 100° C. Comparison of the weights of samples after four hours' drying at 100° C. with the weights of the same samples after five hours' drying at 100° C. shows that the extra hour resulted in a very small loss in weight. It is, therefore, assumed that the weight of the samples after five hours' drying at 100° C. shows the lowest weight that may be obtained by driving off moisture. In other words, weights of the samples after heating five hours at 100° C. are considered moisture-free, and the difference between these weights and the original air-dry weights represents the moisture contained in the air-dry samples, and this figure is used as the basis for calculating the percentage of moisture lost.

TABLE 2.—*Results of conditioning wool samples.*

a. WEIGHTS OF WOOL SAMPLES.

Grade of sample.	Sample No.	Air-dry.	Dried at 50° C.			Dried at 100° C.		
			End first hour.	End second hour.	End third hour.	End third hour.	End fourth hour.	End fifth hour.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Idaho fine medium	10	207.9	196.3	190.7	188.0	174.96	170.78	168.10
Delaine	11	152.1	143.5	140.5	139.2	133.63	132.17	131.15
Do	12	203.1	193.7	187.5	187.7	180.16	177.54	175.61
Idaho fine medium, very dirty	15	211.7	199.6	195.1	192.5	177.52	176.57	174.47
Do	17	212.0	199.6	195.0	192.6	180.52	179.12	177.49

b. WEIGHT OF MOISTURE LOST.

Grade of sample.	Sample No.	Air-dry.	End first hour.	End second hour.	End third hour.	End third hour.	End fourth hour.	End fifth hour.
Idaho fine medium	10	207.9	11.6	17.2	19.9	32.94	37.12	39.8
Delaine	11	152.1	8.6	11.6	12.9	18.47	19.93	20.95
Do	12	203.1	9.4	15.5	15.4	22.94	25.56	27.49
Idaho fine medium, very dirty	15	211.7	12.1	16.6	19.2	34.18	35.13	37.23
Do	17	212.0	12.4	17.0	19.4	31.48	32.88	34.51

TABLE 2.—*Results of conditioning wool samples*—Continued.

c. PER CENT OF MOISTURE LOST.

Grade of sample.	Sample No.	Dried at 50° C.			Dried at 100° C.		
		End first hour.	End second hour.	End third hour.	End third hour.	End fourth hour.	End fifth hour.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Idaho fine medium	10	29.15	43.22	50.00	82.76	93.27	100
Delaine	11	41.05	55.37	61.58	88.16	95.13	100
Do	12	34.19	56.38	56.02	83.44	92.97	100
Idaho fine medium, very dirty	15	32.50	44.59	51.57	91.81	94.36	100
Do	17	35.93	49.26	56.21	91.22	95.28	100

Table 2-*c* shows that conditioning for three hours at 50° C. removed from 50 per cent to 61.5 per cent of the moisture contained in the air-dry wool tested. The calculations previously shown for the theoretical cases of samples A and B are therefore in line with actual tests shown in Table 2. These results, therefore, form the basis for the decision that conditioning wool samples at 50° C. for three hours is sufficient to permit scouring experiments to be conducted within reasonable limits of error. As sufficient accuracy is possible by conditioning at 50° C. for three hours while moisture-free conditioning would require a great deal more time and expense, all samples used in the wool laboratory tests at Beltsville, Md., are conditioned for three hours at 50° C.

The same samples as were used for the tests reported in Table 1 were also dried at 80° C. and records kept of the percentages of loss in moisture at the end of each hour for a period of three hours. All percentages in regard to the less-moist samples are based on the air-dry weights of the less-moist samples, and all percentages in regard to the more-moist samples are based on the air-dry weights of the more-moist samples. The results of this experiment are given in Table 3.

TABLE 3.—*Wool samples with different amounts of moisture, weighed at end of each hour while drying for a period of three hours at 80° C.*

Sample.	Less-moist sample, air-dry weight.	More-moist sample, air-dry weight.	Less-moist sample, weight after 1 hour.	More-moist sample, weight after 1 hour.	Less-moist sample, per cent lost in moisture in 1 hour.	More-moist sample, per cent lost in moisture in 1 hour.	Less-moist sample, weight after 2 hours.	More-moist sample, weight after 2 hours.	Less-moist sample, per cent lost in moisture in 2 hours.	More-moist sample, per cent lost in moisture in 2 hours.	Less-moist sample, weight after 3 hours.	More-moist sample, weight after 3 hours.	Less-moist sample, per cent lost in moisture in 3 hours.	More-moist sample, per cent lost in moisture in 3 hours.
	Gms.	*Gms.*	*Gms.*	*Gms.*	*P. ct.*	*P. ct.*	*Gms.*	*Gms.*	*P. ct.*	*P. ct.*	*Gms.*	*Gms.*	*P. ct.*	*P. ct.*
1	267.3	285.4	257.7	268.7	3.59	5.85	251.7	260.7	5.83	8.65	248.4	257.7	7.07	9.71
2	267.7	282.5	258.3	267.1	3.51	5.45	252.7	260.2	5.60	7.89	249.7	255.5	6.72	9.56
3	269.6	284.1	259.3	269.2	3.82	5.24	254.7	262.4	5.52	7.63	251.8	257.8	6.60	9.25
4	269.2	282.7	260.0	268.3	3.41	5.09	254.6	261.7	5.42	7.43	251.6	257.2	6.53	9.02
5	267.8	283.6	257.5	266.8	3.84	5.92	252.1	259.5	5.86	8.49	249.3	254.9	6.90	10.12
6	267.2	282.6	255.5	264.3	4.37	6.47	249.5	256.2	6.62	9.34	246.7	252.0	7.67	10.82
7	265.9	281.0	253.5	262.9	4.66	6.44	248.9	255.6	6.39	9.04	245.7	250.8	7.59	10.74
8	268.9	282.3	257.5	266.1	4.23	5.73	252.7	259.5	6.02	8.07	250.8	255.4	6.73	9.52
9	269.3	284.0	257.4	265.8	4.41	6.40	252.3	259.1	6.31	8.77	249.1	254.7	7.50	10.31
Average	268.1	283.13	257.41	266.57	3.98	5.84	252.13	259.4	5.95	8.37	249.23	255.11	7.03	9.89

An analysis of Table 3 shows that the more-moist samples, air-dry, averaged 15.03 grams heavier than the same samples of wool when less moist and air dry, while the more-moist samples averaged only 5.88 grams heavier than the less-moist samples after conditioning three hours at 80° C. In other words, the average difference in weight due to moisture content was reduced by conditioning three hours at 80° C. to 39.1 per cent of the original difference between the more-moist samples air dry and the less-moisture samples air dry. It will also be noted that the more-moist samples consistently lost more moisture each hour during the conditioning process than was lost from the less-moist samples.

In like manner the same samples as were used in the tests reported in Table 3 were used to study the effects of conditioning at 50° C. The samples were weighed air-dry and dried at 50° C. for three hours and weighed at the end of each hour. The same samples were then allowed to take on more moisture and weighed again in a similar manner. All percentages in regard to both the less-moist and more-moist samples are based on the air-dry weight.

TABLE 4.—*Wool samples, with different amounts of moisture, weighed at the end of each hour while drying for a period of three hours at 50° C.*

Sample.	Less-moist sample, air-dry weight.	More-moist sample, air-dry weight.	Less-moist sample, weight after 1 hour.	More-moist sample, weight after 1 hour.	Less-moist sample, per cent lost in moisture in 1 hour.	More-moist sample, per cent lost in moisture in 1 hour.	Less-moist sample, weight after 2 hours.	More-moist sample, weight after 2 hours.	Less-moist sample, per cent lost in moisture in 2 hours.	More-moist sample, per cent lost in moisture in 2 hours.	Less-moist sample, weight after 3 hours.	More-moist sample, weight after 3 hours.	Less-moist sample, per cent lost in moisture in 3 hours.	More-moist sample, per cent lost in moisture in 3 hours.
	Gms.	*Gms.*	*Gms.*	*Gms.*	*P. ct.*	*P. ct.*	*Gms.*	*Gms.*	*P. ct.*	*P. ct.*	*Gms.*	*Gms.*	*P. ct.*	*P. ct.*
1	272.5	284.9	267.4	274.2	1.87	3.75	264.5	269.3	2.93	5.47	263.5	266.2	3.30	6.56
2	272.8	283.4	266.0	271.7	2.49	4.12	263.3	266.3	3.48	6.03	262.0	263.2	3.95	7.13
3	271.1	282.0	263.7	270.3	2.73	4.14	261.2	264.8	3.65	6.09	259.7	261.6	4.21	7.23
4	273.3	283.9	266.9	273.4	2.34	3.69	264.3	267.7	3.29	5.70	262.8	264.9	3.84	6.69
5	274.0	282.6	266.5	270.4	2.73	4.31	263.7	264.2	3.75	6.51	261.3	262.3	4.63	7.18
6	303.0	311.8	295.4	306.3	2.51	1.76	292.4	294.5	3.49	5.54	291.1	291.3	3.92	6.57
7	272.0	282.7	266.2	271.6	2.13	3.92	263.5	266.4	3.12	5.76	262.5	263.5	3.49	6.79
8	269.7	278.5	262.6	267.3	2.63	4.02	260.0	262.0	3.59	5.92	259.1	259.2	3.93	6.92
9	277.5	286.8	269.9	275.3	2.73	4.01	267.0	269.3	3.78	6.10	266.0	266.6	4.14	7.04
Average	276.2	286.28	269.4	275.61	2.46	3.72	266.65	269.38	3.45	5.90	265.33	266.53	3.93	6.90

The weights presented in Table 4 show that the more-moist samples, air-dry, averaged 10.08 grams heavier than when they were less moist but air dry. After conditioning for three hours at 50° C. there was an average difference of only 1.2 grams between the more-moist and less-moist samples. The conditioning for three hours at 50° C., therefore, resulted in reducing the difference in weight due to moisture so that at the end of the three hours the average difference was only 11.9 per cent as great as it was before conditioning. The final difference in the case of sample 8 was only 0.1 gram, which was the smallest difference found in this test, while the greatest

final difference was 2.7 grams in the case of sample 1. Using the air-dry weights of the less-moist samples as the basis for percentages, this difference of 2.7 grams amounts to only 0.99 per cent of the air-dry weight of the original sample, and the average difference of 1.2 grams is only 0.43 per cent of the average air-dry weight of the less-moist samples, while the smallest difference of 0.1 gram in the case of sample 8 amounts to only 0.037 per cent, all of which are negligible.

In view of the fact that these experiments showed no advantage in conditioning wool at a higher temperature, it was decided to condition samples at 50° C. The object is to obtain a basic or "conditional" weight, and on the basis of these experiments, 50° C. for three hours seemed to offer this condition when there is no more than 20 per cent of moisture in the air-dry samples. In the experiments here reported, 20 per cent moisture was the largest percentage for any of the samples used. Results of these experiments prove that the drying of wool samples containing no more than the usual amount of moisture for three hours at 50° C. is sufficient to remove all excess of moisture that would cause an appreciable error in the determination of grease, dirt, and clean-wool contents of raw wool.

DETERMINING WEIGHT OF GREASE.

The preceding discussion shows that in order to bring the samples to a constant-moisture content it is necessary to condition them three times before each of the three weighings in the process. It is equally important that all the grease be removed between the first and second conditionings in order to obtain the grease content distinct from the dirt.

The results of tests, involving a series of gasoline treatments on 20 Rambouillet and 20 crossbred[3] fleece samples (in which was shown the percentage of grease removed by each gasoline extraction until free from grease), form the basis for other tests to determine the exact number of treatments necessary to remove all grease. Table 5 shows the results from the 20 Rambouillet and the 20 crossbred wool samples.

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[3] The crossbred sheep used in this investigation are the result of mating Rambouillet ewes with rams of coarse-wool breeds, and the interbreeding of such crosses; also sheep of the Corriedale breed.

TABLE 5.—*Grease removed by a series of gasoline treatments, conditioning between treatments.*

RAMBOUILLET FLEECE SAMPLES.

Sample No.	Conditioned weight of raw wool.	Cumulative weight of grease removed at each treatment (grams).				Cumulative per cent of grease removed at each treatment.				Per cent difference between 1st and 2d treatments.	Per cent difference between 2d and 3d treatments.	Per cent difference between 3d and 4th treatments.	Per cent total grease removed at—[1]		
		First.	Second.	Third.	Fourth.	First.	Second.	Third.	Fourth.				First.	Second.	Third.
2779	234.7	40.3	46.9	49.1	49.9	17.17	19.98	20.92	21.26	2.81	0.94	0.34	80.76	93.98	98.39
2826	230.1	36.2	42.7	44.7	44.7	15.73	18.55	19.42	19.42	2.82	.87	.00	80.98	95.52	100.00
2936	233.5	24.0	28.1	30.3	30.3	10.27	12.03	12.97	12.97	1.76	.94	.00	79.21	92.73	100.00
2968	234.2	36.6	41.5	43.6	44.0	15.62	17.71	18.61	18.78	2.09	.90	.17	83.18	94.31	99.09
2411	222.0	28.5	32.3	33.3	34.1	12.83	14.54	15.00	15.36	1.71	.46	.36	83.57	94.72	97.65
2474	232.9	49.6	56.8	59.4	59.5	21.29	24.38	25.50	25.54	3.09	1.12	.04	83.36	95.46	99.83
2698	232.1	35.9	40.8	42.9	43.2	15.46	17.57	18.48	18.61	2.11	.91	.13	83.1	94.44	99.31
3137	231.6	28.8	33.7	35.7	35.9	12.43	14.55	15.41	15.5	2.12	.86	.09	80.22	93.87	99.44
2136	237.8	37.7	42.9	44.7	44.7	15.85	18.04	18.79	18.79	2.19	.75	.00	84.34	95.97	100.00
2147	228.4	38.2	44.4	46.5	46.8	16.72	19.43	20.35	20.49	2.71	.92	.14	81.62	94.87	99.35
2151	232.4	33.3	38.6	39.4	39.5	14.32	16.61	16.95	16.99	2.29	.34	.04	84.3	97.72	99.74
2747	234.6	31.4	36.4	38.3	38.4	13.38	15.51	16.32	16.36	2.13	.81	.04	81.77	94.79	99.73
1656	229.1	32.3	37.3	39.1	[2]38.7	14.09	16.28	17.06	[2]16.89	2.19	.78	[2]— .17	83.46	96.38	[2]101.03
1779	239.3	43.5	49.6	51.4	51.7	18.17	20.72	21.47	21.6	2.55	.75	.13	84.13	95.93	99.41
1824	236.3	36.7	42.4	44.5	44.5	15.53	17.94	18.83	18.83	2.41	.89	.00	82.47	95.28	100.00
1875	218.3	27.2	31.5	33.6	[2]33.2	12.45	14.42	15.39	[2]15.21	1.97	.97	[2]— .18	81.92	94.87	[2]101.20
1216	235.1	34.5	39.9	41.2	[2]40.9	14.67	16.97	17.52	[2]17.39	2.30	.55	[2]— .13	84.35	97.55	[2]100.73
1240	228.8	33.3	37.8	39.5	39.6	14.55	16.52	17.26	17.31	1.97	.74	.05	84.09	95.45	99.74
1251	229.0	32.5	37.4	39.2	39.2	14.19	16.33	17.11	17.11	2.14	.78	.00	82.91	95.41	100.00
1284	237.4	37.3	41.8	43.5	[2]43.0	15.71	17.61	18.32	[2]18.11	1.9	.71	[2]— .21	86.74	97.21	[2]101.16
Average	231.9	34.9	40.1	42.0	42.1	15.04	17.31	18.11	18.15	2.27	.80	.04	82.89	95.36	99.77

CROSSBRED FLEECE SAMPLES.

Sample No.	Conditioned weight of raw wool.	First.	Second.	Third.	Fourth.	First.	Second.	Third.	Fourth.	Per cent difference between 1st and 2d treatments.	Per cent difference between 2d and 3d treatments.	Per cent difference between 3d and 4th treatments.	First.	Second.	Third.
A-227	240.2	31.8	33.9	37.5	37.6	13.23	14.11	15.15	15.65	0.88	1.04	0.50	84.57	90.15	99.73
A-287	247.4	35.7	38.3	41.9	42.6	14.43	15.48	16.93	17.21	1.05	1.45	.28	83.80	89.91	98.35
A-364	244.3	31.6	33.9	37.6	38.4	12.93	13.87	15.39	15.71	.94	1.52	.32	82.29	88.28	97.91
A-440	246.0	29.3	31.3	36.5	36.6	11.91	12.72	14.83	14.87	.81	2.11	.04	80.05	85.51	99.72
B-742	240.7	26.5	27.4	31.8	32.4	11.01	11.38	13.21	13.46	.37	1.83	.25	81.79	84.56	98.14
B-799	239.6	28.5	31.1	35.2	35.6	11.89	12.97	14.69	14.85	1.08	1.72	.16	80.05	87.35	98.87
B-887	239.9	25.3	27.5	32.4	32.6	10.54	11.46	13.51	13.58	.92	2.05	.07	77.61	84.35	99.38
Lcn. 211	242.0	38.8	44.2	46.4	47.6	16.03	18.26	19.17	19.66	2.23	.91	.49	81.51	92.85	97.47
Lcn. 244	238.0	29.1	31.4	35.6	36.2	12.22	13.19	14.95	15.21	.97	1.76	.26	80.38	86.74	98.34
Lcn. 460	249.2	26.5	29.2	33.7	34.0	10.63	11.71	13.52	13.64	1.08	1.81	.12	77.94	85.88	99.11
Lcn. 511	240.1	21.1	22.4	26.6	27.2	8.78	9.32	11.07	11.32	.54	1.75	.25	77.57	82.35	97.79
Cla. 96	236.6	25.9	27.2	31.3	32.1	10.94	11.49	13.22	13.56	.55	1.73	.34	80.68	84.73	97.51
Cla. 101	239.8	34.9	39.4	44.1	45.7	14.55	16.43	18.39	19.05	1.88	1.96	.66	76.36	86.21	96.49
Cla. 112	241.0	25.3	29.0	33.2	35.1	10.49	12.03	13.77	14.56	1.54	1.74	.79	72.07	82.62	94.58
Cts. 63	241.2	17.9	19.5	21.0	23.6	7.42	8.08	8.71	9.78	.66	.63	1.07	75.84	82.62	88.98
C-260	243.5	18.7	20.7	24.6	25.2	7.67	8.50	10.10	10.34	.83	1.60	.24	74.21	82.14	97.61
D-188	243.7	24.3	27.2	30.4	30.9	9.97	11.16	12.47	12.67	1.19	1.31	.20	78.64	88.02	98.38
E-211	241.2	29.8	32.6	36.2	36.6	12.35	13.51	15.01	15.17	1.16	1.50	.16	81.42	89.07	98.91
O-94	245.0	42.0	45.7	49.8	50.3	17.14	18.65	20.32	20.53	1.51	1.67	.21	83.49	90.85	99.01
U. S. 168	248.6	43.6	47.8	50.9	51.8	17.53	19.22	20.47	20.83	1.69	1.25	.36	84.16	92.27	98.26
Average	242.4	29.3	32.0	35.8	36.6	12.09	13.19	14.78	15.10	1.10	1.59	.32	80.12	87.37	97.89

[1] In calculating the percentage of grease in the last three columns the amount of grease removed by 4 gasoline treatments is accepted as the total amount contained in the samples and is used as a basis, because the per cent of difference between the grease removed by the third and by the fourth treatment is shown to be negligible, the average being only 0.3.

[2] The weight of grease removed is determined by the subtraction of the conditioned weight of degreased wool from the conditioned weight of greasy wool. It is shown in the previous discussion that not all moisture is removed by conditioning. However, variation in moisture content of conditioned wool is not sufficient to cause appreciable error. Consequently slight errors caused by overweight due to moisture in the degreased samples occur at times but are not sufficient to affect the value of the final results.

The average results in Table 5 show that from the Rambouillet fleece samples the grease removed by one treatment was 15.04 per cent of the conditioned weight of raw wool; 17.31 by two; 18.11 by three; and 18.15 by four. The average results from the crossbred fleece samples were 12.09 per cent of grease removed by one treatment; 13.19

by two; 14.78 by three; and 15.10 by four. This indicates that after three treatments of gasoline the remaining grease is not sufficient to cause any appreciable error, there being only 0.04 per cent removed by the fourth treatment from the Rambouillet samples and 0.32 per cent from the crossbred.

The results of three other runs of 20 samples each of Rambouillets and crossbreds (based on the results of Table 5, which show that three is the least number of treatments which can be used) show in Table 6 the amount of grease removed by each extraction above the third until the samples are free from grease.

TABLE 6.—*Grease removed by gasoline treatments, conditioning after the third and after each succeeding treatment.*

RAMBOUILLET FLEECE SAMPLES.

Sample No.	Conditioned weight of raw wool. (grams).	Cumulative weight of grease removed at treatment (grams).		Cumulative per cent of grease removed at treatment.		Per cent grease removed by fourth treatment.	Per cent total grease removed by three treatments.
		Third.	Fourth.	Third.	Fourth.		
801	239.8	40.3	40.5	16.81	16.88	−0.07	99.51
U. S. 77	233.6	35.9	[1] 35.6	15.36	[1] 15.23	[1] −.13	[1] 100.84
1303	242.4	61.6	62.2	25.41	25.66	.25	99.03
1305	241.0	42.4	42.7	17.59	17.71	.12	99.29
2058	235.7	37.1	37.7	15.74	15.99	.25	98.41
2080	239.9	45.1	45.4	18.79	18.92	.13	99.33
2141	237.4	40.6	40.7	17.1	17.14	.04	99.75
2151	236.6	34.6	34.6	14.62	14.62	.00	100.00
2268	238.6	40.7	[1] 40.4	17.05	[1] 16.93	[1] − .12	[1] 100.74
2353	236.4	37.6	[1] 37.3	15.91	[1] 15.77	[1] − .14	[1] 100.80
2356	239.3	54.9	[1] 54.5	22.94	[1] 22.77	[1] − .17	[1] 100.73
2366	240.6	42.6	45.0	17.71	18.70	.99	94.66
2413	239.1	49.6	[1] 49.5	20.74	[1] 20.70	[1] −.04	[1] 100.20
2569	235.6	28.5	[1] 27.2	12.09	[1] 11.54	[1] −.55	[1] 104.77
2686	240.0	40.8	41.9	17.00	17.45	.45	97.37
2724	236.4	37.9	38.1	16.03	16.11	.08	99.47
2753	237.5	27.9	28.3	11.74	11.91	.17	98.58
2758	233.6	23.0	24.7	9.84	10.57	.73	93.11
2910	236.6	35.2	[1] 35.1	14.87	[1] 14.83	[1] −.04	[1] 100.28
2911	239.0	29.2	29.7	12.21	12.42	.21	98.31
588	239.5	44.3	45.4	18.49	18.95	.46	97.57
1101	239.6	32.1	32.6	13.39	13.61	.22	98.46
1125	242.9	42.3	43.3	17.41	17.82	.41	97.69
1201	236.7	44.5	46.5	18.80	19.64	.84	95.69
1350	239.8	51.7	53.7	21.55	22.39	.84	96.27
1387	244.2	44.0	45.1	18.01	18.46	.45	97.56
1850	236.2	34.7	35.8	14.69	15.15	.46	96.92
2360	240.4	46.8	48.0	19.46	19.96	.50	97.50
2410	237.1	40.5	42.2	17.08	17.79	.71	95.97
2434	237.1	29.3	30.5	12.35	12.86	.51	96.06
2470	239.2	34.2	35.2	14.29	14.71	.42	97.15
2471	236.7	41.0	41.3	17.32	17.44	.12	99.27
2582	234.5	28.1	[1] 28.0	11.98	[1] 11.94	[1] −.04	[1] 100.35
2643	254.2	47.3	47.8	18.61	18.80	.19	98.95
2666	239.3	37.3	37.9	15.58	15.83	.25	98.41
2819	239.2	53.7	54.0	22.44	22.57	.13	99.44
2931	235.1	26.1	26.2	11.10	11.14	.04	99.61
2937	235.3	35.1	[1] 35.0	14.91	[1] 14.87	[1] −.04	[1] 100.28
2999	234.6	28.5	[1] 28.4	12.14	12.11	[1] −.03	[1] 100.35
3137	230.4	30.3	[1] 30.2	13.15	13.11	[1] −.04	[1] 100.33
594	239.5	29.7	[1] 29.6	12.40	[1] 12.35	[1] −.05	[1] 100.33
1089	237.6	32.7	[1] 32.5	13.76	[1] 13.67	[1] −.09	[1] 100.61
1122	231.4	30.0	31.0	12.96	13.39	.43	96.77
1177	236.8	40.5	40.9	17.10	17.27	.17	99.02
1205	235.3	33.2	33.8	14.11	14.36	.25	98.22
1336	238.9	32.1	32.8	13.43	13.72	.29	97.86
1345	242.2	45.9	[1] 45.7	18.95	[1] 18.86	[1] −.09	[1] 100.43
1630	238.3	52.5	54.0	22.03	22.66	.63	97.22
1823	239.9	63.5	63.6	26.46	26.51	.05	99.84
2068	253.3	50.7	50.7	20.01	20.01	.00	100.00
2194	238.4	40.4	[1] 39.3	16.94	[1] 16.48	[1] −.46	[1] 102.79
2343	240.3	41.8	[1] 41.6	17.39	[1] 17.31	[1] −.08	[1] 100.48
2548	237.9	35.7	36.3	15.01	15.25	.24	98.34

[1] See footnote 2 under Table 5.

TABLE 6.—*Grease removed by gasoline treatments, conditioning after the third and after each succeeding treatment*—Continued.

RAMBOUILLET FLEECE SAMPLES—Continued.

Sample No.	Conditioned weight of raw wool (grams).	Cumulative weight of grease removed at treatment (grams).		Cumulative per cent of grease removed at treatment.		Per cent grease removed by fourth treatment.	Per cent total grease removed by three treatments.
		Third.	Fourth.	Third.	Fourth.		
2706	237.0	39.5	39.6	16.66	16.71	0.05	99.74
2713	237.2	32.9	32.9	13.87	13.87	.00	100.00
2754	235.7	41.7	42.2	17.69	17.90	.21	98.81
2956	227.5	37.5	37.5	16.48	16.48	.00	100.00
3015	241.5	54.6	54.7	22.61	22.65	.04	99.81
3073	244.2	46.3	[1] 45.9	18.95	[1] 18.79	[1] −.16	[1] 100.87
33-R	246.8	46.6	46.6	18.88	18.88	.00	100.00
Average	238.5	39.8	40.2	16.66	16.83	.17	98.99

CROSSBRED FLEECE SAMPLES.

Sample No.	Conditioned weight of raw wool (grams).	Third.	Fourth.	Third.	Fourth.	Per cent grease removed by fourth treatment.	Per cent total grease removed by three treatments.
Lcn. 397	238.4	40.8	[1] 40.7	17.11	[1] 17.07	[1] −0.04	[1] 100.24
Lcn. 507	239.8	53.4	53.7	22.26	22.39	.13	99.44
Rmy. 48	245.0	30.9	32.1	12.61	13.10	.49	96.26
A-24	246.5	47.3	49.4	19.18	20.04	.86	95.74
A-48	237.1	33.6	33.7	14.17	14.21	.04	99.70
A-220	239.4	35.1	36.0	14.66	15.03	.37	97.50
A-295	244.8	25.0	[1] 24.8	10.21	[1] 10.13	[1] −.08	[1] 100.80
A-480	230.2	36.3	37.0	15.76	16.07	.31	98.11
B-335	236.9	28.8	29.0	12.15	12.24	.09	99.31
B-355	216.9	37.2	[1] 37.1	17.15	[1] 17.10	[1] −.05	[1] 100.26
B-545	234.0	29.7	29.7	12.69	12.69	.00	100.00
B-565	220.0	22.6	23.0	10.27	10.45	.28	98.26
C-144	240.5	33.6	34.2	13.97	14.22	.25	98.24
C-157	241.7	23.7	24.4	9.81	10.09	.28	97.13
D-26	238.0	26.8	26.8	11.26	11.26	.00	100.00
E-37	236.4	41.7	45.4	17.63	19.20	1.57	91.85
E-167	235.3	23.0	24.5	9.77	10.41	.64	93.87
O-46	236.6	23.4	23.4	9.89	9.89	.00	100.00
O-96	249.4	30.6	30.7	12.26	12.31	.05	99.67
U. S. 32	253.2	52.4	52.7	20.69	20.81	.12	99.43
Lcn. 439	255.8	26.7	26.7	10.43	10.43	.00	100.00
Lcn. 467	240.7	22.8	22.8	9.47	9.47	.00	100.00
Lcn. 472	237.8	28.9	30.0	12.15	12.61	.46	96.33
Lcn. 475	251.9	27.8	27.9	11.03	11.07	.04	99.64
Cla. 61	237.6	16.4	17.7	6.90	7.44	.54	92.65
A-5	250.0	32.2	32.2	12.88	12.88	.00	100.00
A-70	294.9	37.5	[1] 37.4	12.71	[1] 12.68	[1] −.03	[1] 100.26
B-5	254.8	33.1	33.5	12.99	13.14	.15	98.81
B-352	239.7	34.1	34.1	14.22	14.22	.00	100.00
B-409	181.4	26.3	26.7	14.49	14.71	.22	98.50
B-451	234.2	36.3	36.9	15.49	15.75	.26	98.37
B-579	260.1	31.6	31.6	12.14	12.14	.00	100.00
C-58	239.6	27.3	28.3	11.39	11.81	.42	96.46
C-159	238.0	28.7	30.6	12.05	12.85	.80	93.79
C-191	242.7	23.3	25.3	9.60	10.42	.82	92.09
D-8	241.5	19.3	19.7	7.99	8.15	.16	97.96
E-42	237.7	30.1	30.8	12.66	12.95	.29	97.72
E-165	250.4	16.7	17.5	6.66	6.98	.32	95.42
O-106	235.5	22.2	22.9	9.42	9.72	.30	96.94
U. S. 7	238.1	39.3	39.6	16.51	16.63	.12	99.24
Lcn. 160	240.8	30.3	30.5	12.58	12.66	.08	99.34
Lcn. 388	239.4	24.6	25.1	10.27	10.48	.21	98.01
Lcn. 498	245.3	35.1	35.2	14.31	14.34	.03	99.71
O-70	244.9	33.1	33.8	13.51	13.80	.29	97.92
Cla. 54	261.3	29.9	30.1	11.44	11.51	.07	99.33
Cla. 138	239.6	35.9	37.2	14.98	15.52	.54	96.51
A-68	250.0	32.6	33.2	13.04	13.28	.24	98.19
A-423	254.0	28.8	28.8	11.33	11.33	.00	100.00
A-487	235.3	26.9	28.8	11.43	12.23	.80	93.40
B-28	253.6	28.6	29.9	11.27	11.79	.52	95.65
B-626	239.3	27.1	28.9	11.32	12.07	.75	93.77
B-821	234.9	22.2	22.2	9.45	9.45	.00	100.00
Lst. 21	235.5	21.9	[1] 21.6	9.29	[1] 9.17	[1] −.12	[1] 101.38
D-18	235.1	26.0	27.1	11.05	11.52	.47	95.94
D-24	240.1	31.9	32.4	13.28	13.49	.21	98.45
O-160	248.9	22.1	24.7	8.87	9.92	1.05	89.47
E-21	228.2	35.6	36.6	15.60	16.03	.43	97.26
E-38	236.4	54.6	55.4	23.09	23.43	.34	98.55
U. S. 37	248.5	49.6	50.2	19.95	20.20	.25	98.80
U. S. 159	228.0	14.6	16.4	6.40	7.19	.79	89.02
Average	241.0	30.8	31.5	12.77	13.05	.28	97.84

[1] See footnote [2] under Table 5.

Table 6 shows that the grease removed from the 60 Rambouillet fleece samples by the first three extractions averaged 16.66 per cent of the conditioned weight of the raw wool, while at the fourth extraction the per cent averaged 16.83, or 0.17 per cent removed by the fourth treatment. From the 60 crossbred samples an average of 12.77 per cent of grease was removed by the first three treatments, and 13.05 per cent by four, or 0.28 per cent by the fourth treatment. From the extremely small amount of grease removed by the fourth extraction in each case, it is assumed that the per cent of grease extracted by the four treatments shows the total quantity of grease contained in the samples, and that the per cent removed by the fourth is negligible. Using the figures obtained from the four extractions as the total amount of grease, and therefore as a basis for calculation, Table 6 shows that 98.99 per cent of the total grease was removed by three extractions from the Rambouillet samples and 97.84 per cent from the crossbred. Since these tests show that only a negligible quantity of grease is removed by the fourth extraction, it has been decided to use three gasoline treatments in the scouring process.

DETERMINING WEIGHT OF DIRT.

Before the third conditioning of the wool in the oven, it is necessary to remove all the dirt in order to obtain the clean-wool weight. A part of the dirt is of course removed with the grease by the gasoline treatments. This is caught by the filter papers and kept with the samples until they are ready to be washed in the tub, when the dirty filter papers are thrown away. The rest of the dirt is removed by means of soap and water in the tub, about half a pound of neutral soap proving to be sufficient for the 150 gallons of water used. The temperature of the water is kept at 40° to 45° C., as trials showed that temperature to be sufficient for the removal of the dirt, without being hot enough to felt the wool. After the wool has been washed, rinsed, and dried in blower and oven, the clean weight of the wool is taken. The weight of dirt is determined by subtracting the weight of clean wool from the weight of degreased wool before the removal of the dirt.

WEEKLY WORKING SCHEDULE.

In order to scour all the samples sent to the laboratory each year, it is necessary to complete 60 each week. Owing to the fact that in the process each set of samples must dry after the various treatments—three hours in the conditioning oven at three different times, about three hours between each of the three gasoline treatments, and eight hours in the blower dryer—it is evident that considerable time elapses between the beginning and the completion of the scouring of each run of samples. For example, a run started on Monday will be completed on Friday.

The laboratory is equipped to handle only 20 samples at a time. Consequently it is important that the runs be arranged in such way that they do not conflict in the use of the apparatus, and that all runs will be handled in the same way as nearly as possible. Therefore, in order to obtain uniformity of treatment and the largest possible weekly output, the following schedule has been worked out. It is so

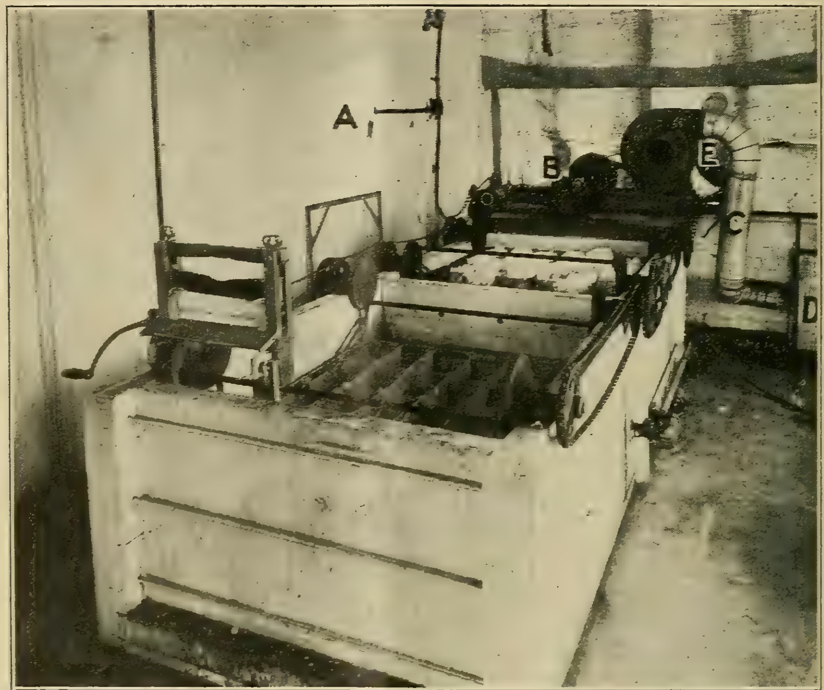

FIG. 5.—Washing apparatus. The empty washing baskets are shown in the first tub and the washing baskets filled with wool in the second tub. When this apparatus is in operation the washing baskets rise, move from end to end, and fall. Note the holes in the partition between the first and second tubs. Water is allowed to rise almost to these holes and is then shut off. In case of an overflow the holes prevent flooding the top. The water is heated by steam pipes in the bottom of each tub. At the right of A is the electric switch button and the motor, B, that drives the washing machinery. The ordinary clothes wringer shown in the foreground is used for wringing water from washed, rinsed wool samples. The air pipe, C, conducts air into tank, D, of the blower-dryer. The heated air returns through the upper part of the blower-dryer, where the baskets of wool are placed for drying, and the air passes out of the dryer through the pipe shown at E.

arranged that it operates in weekly cycles (the work of each day of the week being the same as that of the preceding week). This schedule also has the advantage of rendering possible the picking up of the threads of the process, without delay, in case of change in individual operators in the laboratory.

The different steps outlined below are explained in detail on pages 2, 3, and 4.

Weekly schedule of work at Bureau of Animal Industry Wool Laboratory, Beltsville, Md.

MONDAY.

A. M.

9.00 Place baskets 81–100 in oven empty.
9.25 Weigh baskets 81–100. Take from oven, fill with new wool.
10.00 Put 81–100 in oven for three hours.
10.15 Fold and weigh filter papers.

P. M.

1.00 Weigh baskets 81–100.
4.00 Put gasoline on baskets 81–100.
4.45 Filter.
Blower on all day.

TUESDAY.

A. M.

9.00 Place baskets 21–40 in oven empty.
9.20 Distill gasoline.
9.25 Weigh baskets 21–40. Take from oven, fill with new wool.
10.00 Place baskets 41–60 (clean wool left from preceding week) in oven for three hours.
11.00 Put gasoline on 81–100.
11.45 Filter.

P. M.

1.00 Weigh baskets 41–60.
1.15 Distill gasoline.
1.30 Place baskets 21–40 in oven for three hours.
3.30 Put gasoline on 81–100.
4.15 Filter.
4.30 Weigh 21–40.

WEDNESDAY.

A. M.

9.20 Distill gasoline.
10.00 Place baskets 81–100 in oven for three hours.
10.15 Fold and weigh filter papers.
11.00 Put gasoline on 21–40.
11.45 Filter.

P. M.

1.00 Weigh baskets 81–100.
1.30 Wash 81–100.
2.30 Distill gasoline.
4.00 Put gasoline on 21–40.
4.45 Filter.

THURSDAY.

A. M.

9.00 Place baskets 61–80 in oven empty.
9.20 Distill gasoline.
9.25 Weigh baskets 61–80. Take from oven, put in new wool.
10.00 Place 61–80 in oven for three hours.
10.30 Put gasoline on 21–40.
11.15 Filter.

P. M.

12.00 Place 21–40 in blower for $1\frac{1}{4}$ hours.
1.00 Weigh 61–80.
1.15 Distill gasoline.
1.30 Place 21–40 in oven three hours.
2.00 Fold and weigh filter papers.
3.30 Put gasoline on 61–80.
4.15 Filter.
4.30 Weigh baskets 21–40.
Blower on all day.

FRIDAY.

A. M.

9.20 Distill gasoline.
10.00 Wash 21–40.
11.00 Put gasoline on 61–80.
11.45 Filter.

P. M.

1.30 Place 81–100 in oven for three hours.
1.30 Distill gasoline.
3.30 Put gasoline on 61–80.
4.15 Filter.
4.30 Weigh 81–100.
Blower on from 12 to 5 o'clock.

SATURDAY.

A. M.

9.20 Distill gasoline.
10.00 Place 61–80 in oven for three hours.

P. M.

1.00 Weigh 61–80.
1.30 Place 21–40 in oven for three hours.
1.30 Wash 61–80 in tub.
4.30 Weigh 21–40.
Blower on till noon.

TABLE 7.—*Sample sheet from record book.*

Page..........

Date, October 11, 1921.

BREED: Rambouillet. 1921 WOOL CLIP.

WOOL-SCOURING DATA.

Basket No.	Sample No.	*a* Conditioned weight of sample and basket.	*b* Weight of basket.	*c* Conditioned weight of greasy wool.	*d* Conditioned weight of wool filter paper and basket after extraction.	*e* Weight of filter paper.	*f* Conditioned weight of wool (after extraction) and dirt.	*g* Weight of grease extracted.	*h* Conditioned weight of wool and basket after washing.	*i* Weight of dirt.	*j* Conditioned weight of clean wool.	*k* Per cent grease.	*l* Per cent dirt.	*m* Per cent clean wool.	*n* Grease index.	*o* Dirt index.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*	*Per cent.*	*Per cent.*		
21	561	560.5	313.6	246.9	550.6	30.6	206.4	40.5	422.1	97.9	108.5	16.40	39.65	43.94	37.32	90.23
22	1304	542.5	316.4	226.1	523.7	30.8	176.5	49.6	412.6	80.3	96.2	21.93	35.51	42.54	51.55	83.47
23	1318	540.2	317.0	223.2	523.9	30.6	176.3	46.9	417.4	75.9	100.4	21.01	34.01	44.98	46.71	75.59
24	1334	558.8	316.3	242.5	530.4	29.7	214.1	28.4	418.6	111.8	102.3	11.71	46.10	42.18	27.76	109.28
25	1405	556.0	317.8	238.2	553.9	30.4	205.7	32.5	438.1	85.4	120.3	13.64	35.85	50.50	27.01	70.98
26	1416	560.6	320.7	239.9	547.6	30.1	196.8	43.1	453.9	63.6	133.2	17.96	26.51	55.52	32.35	47.74
27	1652	550.6	312.2	238.4	520.7	31.2	177.3	61.1	422.2	67.3	110.0	25.62	28.22	46.14	55.54	61.18
28	1722	554.5	313.8	240.7	531.4	30.5	187.1	53.6	409.5	91.4	95.7	22.26	37.97	39.75	56.01	95.51
29	2092	562.4	324.9	237.5	535.5	30.7	179.9	57.6	427.0	77.8	102.1	24.25	32.75	42.98	56.41	76.19
30	2301	563.8	320.8	243.0	546.6	30.2	195.6	47.4	440.3	76.1	119.5	19.51	31.31	49.17	39.66	63.68
31	2302	541.0	308.7	232.3	525.0	31.3	185.0	47.3	424.2	69.5	115.5	20.36	29.91	49.72	40.95	60.17
32	2332	549.5	307.7	241.8	542.3	29.3	205.3	36.5	437.4	75.6	129.7	15.09	31.26	53.63	28.14	58.28
33	2840	544.5	310.4	234.1	523.4	30.0	183.0	51.1	440.4	53.0	130.0	21.82	22.63	55.53	39.31	40.76
34	2845	566.1	322.2	243.9	554.1	30.2	201.7	42.2	446.6	77.3	124.4	17.30	31.69	51.00	33.92	62.13
35	2860	542.9	304.5	238.4	543.3	30.5	208.3	30.1	423.5	89.3	119.0	12.62	37.45	49.91	25.29	75.04
36	2936	543.2	310.3	232.9	544.7	30.7	203.7	29.2	456.0	58.0	145.7	12.53	24.90	62.55	20.04	39.81
37	3018	557.0	321.2	235.8	554.7	31.1	202.4	33.4	454.6	69.0	133.4	14.16	29.26	56.57	25.03	51.72
38	3032	548.2	313.7	234.5	533.5	30.7	189.1	45.4	433.5	69.3	119.8	19.36	29.55	51.08	37.89	57.84
39	3059	546.1	311.1	235.0	539.3	30.5	197.7	37.3	422.7	86.0	111.7	15.87	36.59	47.53	33.39	76.99
40	3122	550.9	313.2	237.7	535.1	29.6	191.8	45.9	419.2	85.8	106.0	19.31	36.09	44.59	43.30	80.94

EXPLANATION OF WOOL-SCOURING DATA SHEET.

Actual weights taken in the laboratory are recorded as shown in Table 7 in columns *a, b, d, e,* and *h*. All weights of wool shown on data sheet are conditioned weights. The others are filled in from calculations made from *a, b, d, e,* and *h*. The following formulas show the calculation used to obtain the figures of each column.

$a-b=c$	$f-j=i$
$d-(b+e)=f$	$100\ i \div c=l$
$c-f=g$	$100\ j \div c=m$
$h-b=j$	$100\ g \div j=n$
$100\ g \div c=k$	$100\ i \div j=o$

or:

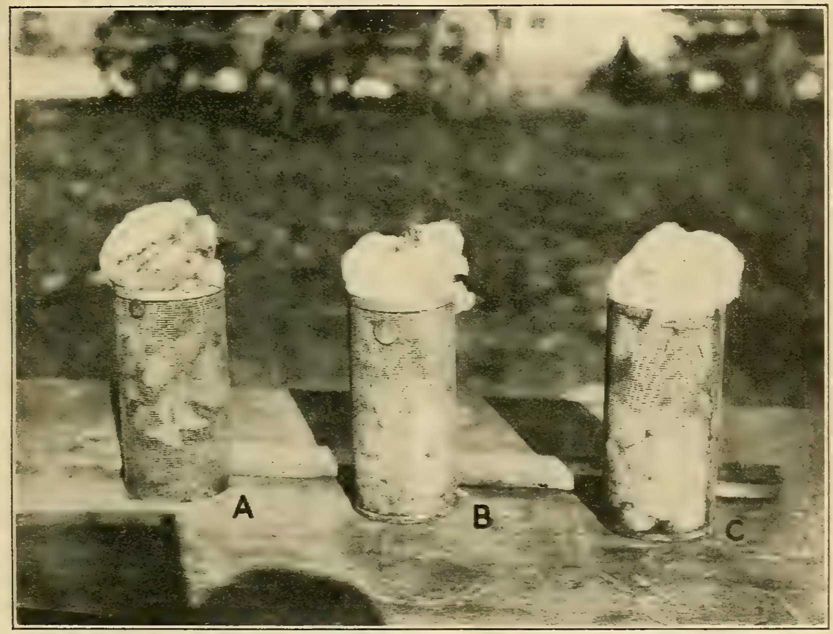

FIG. 6.—Baskets of wool. A, raw wool before scouring. B, degreased wool, dirt remaining. C, clean, scoured wool, free from grease and dirt.

The weight of basket (*b*) subtracted from the conditioned weight of sample and basket (*a*) gives the conditioned weight of greasy wool (*c*).

The weight of basket (*b*) and weight of filter paper (*e*) subtracted from the conditioned weight of wool, filter paper, and basket after extraction (*d*) gives the conditioned weight of wool and dirt after extraction (*f*).

The conditioned weight of greasy wool (*c*) minus the conditioned weight of wool and dirt after extraction (*f*) gives the weight of grease (*g*).

The conditioned weight of wool and basket after washing (*h*) minus the weight of basket (*b*) gives the conditioned weight of clean wool (*j*).

The weight of grease (*g*) divided by the weight of greasy wool (*c*) gives the per cent of grease in the sample (*k*).

The conditioned weight of wool and dirt after extraction (*f*) minus the conditioned weight of clean wool (*j*) gives the weight of dirt (*i*).

The weight of dirt (*i*) × 100 divided by the conditioned weight of greasy sample (*c*) gives the per cent of dirt (*l*).

The weight of clean wool (*j*) × 100 divided by the conditioned weight of the greasy sample (*c*) gives the per cent of clean wool (*m*).

The weight of grease (*g*) × 100 divided by the conditioned weight of clean wool (*j*) gives the grease index (*n*).

The weight of dirt (*i*) × 100 divided by the conditioned weight of clean wool (*j*) gives the dirt index (*o*).

SUMMARY.

Before the scouring process, all samples of wool are brought to a constant-moisture content.

In the moisture experiments here reported, 20 per cent moisture was the largest percentage for any of the samples used.

When there is no more than 20 per cent moisture in air-dry samples, it has not been found necessary to condition them longer than three hours nor at a temperature higher than 50° C.

Grease is removed by washing the samples in gasoline, which is drained off through filter papers in order to retain all foreign matter.

Three gasoline treatments are used in degreasing the wool, since it has been found that only 0.17 per cent of grease remains in Rambouillet wool after three treatments, and 0.28 per cent in crossbred wool.

Dirt is removed from the samples by means of soap and water. A temperature of 40° to 45° C. is used for the water, as trials show that this is sufficient to remove the dirt, without being hot enough to felt the wool.

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PORTLAND CEMENT CONCRETE ROADS

By

JAMES T. VOSHELL, District Engineer

R. E. TOMS, Senior Highway Engineer

Bureau of Public Roads

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Division of Biological Investigations, Bureau of Biological Survey

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By

DAVID GRIFFITHS, Horticulturist
Office of Horticultural and Pomological Investigations
Bureau of Plant Industry

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POSTULATES OF TULIP-BULB PRODUCTION.

(1) Do not plant on lean soil.

(2) Use the most available source of fertility and utilize it to the utmost by a thick and exhaustive planting.

(3) Continually strive to plant back every year as large a percentage of the smallest bulbs that will grow to maturity in one year as is compatible with maintenance of stock.

(4) Do not sell all the large bulbs, but plant back a small number of the largest and best, especially of the varieties which reproduce poorly.

(5) Do not plant on the same ground more often than once in two and preferably once in three years.

(6) Dig and replant every year.

(7) Practice clean culture; keep down weeds.

(8) Preserve the bulb coats; do not let the bulbs mold; handle them without bruising.

(9) Avoid having the broken tulips in close proximity to the breeders or self-colored stocks.

(10) Plant early. The best results are to be expected from plantings made before the end of September.

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COMPILED BY

F. B. LINTON, Assistant to the Chief of the Bureau of Chemistry

From Reports Furnished by a Committee of Food Inspectors of the Bureau of Chemistry, Consisting of J. R. GARNER, G. H. ADAMS, and A. S. DAGGETT

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Live Stock, Meats, and Wool Division
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